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Everett Harbor Action Program: Analysis of Toxic Problem Areas
Puget Sound Estuary Program: Final Report and Appendices
Two Volumes

PTI Environmental Services, Bellevue, WA

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This report presents the results of a field investigation of the nearshore region of the Everett Harbor/Port Gardner/Snohomish River system. Under the Everett Harbor Action Program, federal, state, and local agencies cooperate to respond to toxic contamination problems. Response actions may include regulatory control of point and non-point contamination sources, source treatment, capping or removal of highly contaminated sediments. The study objectives were to: 1) define spatial patterns and quantitative relationships between sediment contamination, toxicity and biological effects; 2) identify problem areas of sediment contamination; 3) rank problem areas for possible remediation; 4) identify potential problem chemicals that display high concentrations in association with biological effects. A standardized assessment technique used in several other Puget Sound Estuary Program urban bay projects was used to identify problem sediments. The primary information used in the problem area ranking process included: 1) sediment characteristics (i.e., contaminant concentrations, conventional physical/chemical characteristics); and 2) biological effects (i.e., benthic invertebrate community structure, sediment toxicity bioassays using amphipods, concentrations of PCB's, chlorinated pesticides and mercury in muscle tissue of English sole, prevalence of liver lesions in English sole).

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EVERETT HARBOR ACTION PROGRAM:

Analysis of Toxic Problem Areas

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FINAL REPORT

September 1988

Prepared by
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and
Tetra Tech, Inc.

Prepared for
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Region X - Office of Puget Sound
Seattle, Washington

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EVERETT HARBOR ACTION PROGRAM: ANALYSIS OF TOXIC PROBLEM AREAS

for

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Region X, Office of Puget Sound
Seattle, WA 98005

September 1988

by

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Analytical Resources, Inc.	Volatile Organic Compounds
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Enseco/California Analytical	Acid/Base/Neutral Organic Compounds, PCBs/Pesticides in Sediments
Laucks Testing Laboratories	Resin Acids, Chlorinated Phenols, Chlorinated Guaiacols
Weyerhaeuser Analytical and Testing Services	Total Organic Carbon, Total Nitrogen

The Everett Harbor Toxics Action Program has benefited from the participation of an Interagency Work Group (IAWG) and a Citizen's Advisory Committee (CAC). Duties of the IAWG and CAC members included: 1) reviewing program documents, agency policies, and proposed actions; 2) providing data reports and other technical information to EPA; and 3) disseminating action program information to respective interest groups or constituencies. We thank the IAWG and CAC members for their past and continuing efforts. We are especially grateful to Ms. Joan Thomas and Mr. Dave Murdock for chairing the IAWG, and to Mr. Gary Wold for chairing the CAC. Members of the IAWG and CAC are listed below.

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EXECUTIVE SUMMARY

The goal of the Everett Harbor Toxics Action Program is to identify and control toxic contamination in the Port Gardner and lower Snohomish River system. Under this program, federal, state, and local agencies cooperate to respond to toxic contamination problems. Response actions may include regulatory control of point and nonpoint sources of contaminants, and treatment, capping, or removal of highly contaminated sediments. The purpose of this report is to identify toxic problem areas and rank them in terms of priority for evaluation of source controls and sediment remedial action. The results of a field investigation (Tetra Tech 1986h) of the nearshore region of the Everett Harbor system performed in August-September 1986 are evaluated to achieve the following objectives:

- Define spatial patterns and quantitative relationships of sediment contamination, toxicity, and biological effects
- Identify problem areas of sediment contamination and associated biological effects
- Rank problem areas relative to priority for evaluation of source controls and sediment remedial action
- Identify potential problem chemicals (i.e., chemicals that display high concentrations in association with adverse biological effects).

Information presented in this report will be used in conjunction with the results of a field survey of contaminant sources to evaluate potential sources and develop recommended source controls in the Everett Harbor system.

The project area is described in the next section. The decision-making approach for problem evaluation, the spatial distribution of contaminants and effects in the Everett Harbor system, and the ranking of problem areas are described in the following sections.

PROJECT AREA

The Everett Harbor project area includes nearshore areas of Port Gardner, the Snohomish River Delta, and the lower Snohomish River estuary (Figure ES-1). For the purpose of this study, Everett Harbor is defined as the area east of a line joining Elliott Point in Mukilteo with the western point of Mission Beach at the entrance of Tulalip Bay. The Snohomish River Delta and the estuary east to Interstate 5 are included in the project area.

The project area watershed encompasses about 280 km^2 of primarily forest and agricultural lands within the Snohomish River basin. Urbanized areas within the watershed include Everett, Mukilteo, and Marysville. Known sources of contaminants include past and current discharges from pulp mills, several sewage treatment plants, and storm drainage channels. Stormwater runoff from urban and agricultural areas enters Everett Harbor via the Snohomish River, many smaller streams, and man-made storm drains.

DECISION-MAKING APPROACH

The approach to identification and ranking of problem areas relies on empirical measurements of the environmental hazard of contaminated areas. The primary information used in the decision process includes:

- **Sediment characteristics**
    - Contaminant concentrations
    - Conventional physical/chemical characteristics (e.g., grain size distribution, sulfides, total organic carbon content)

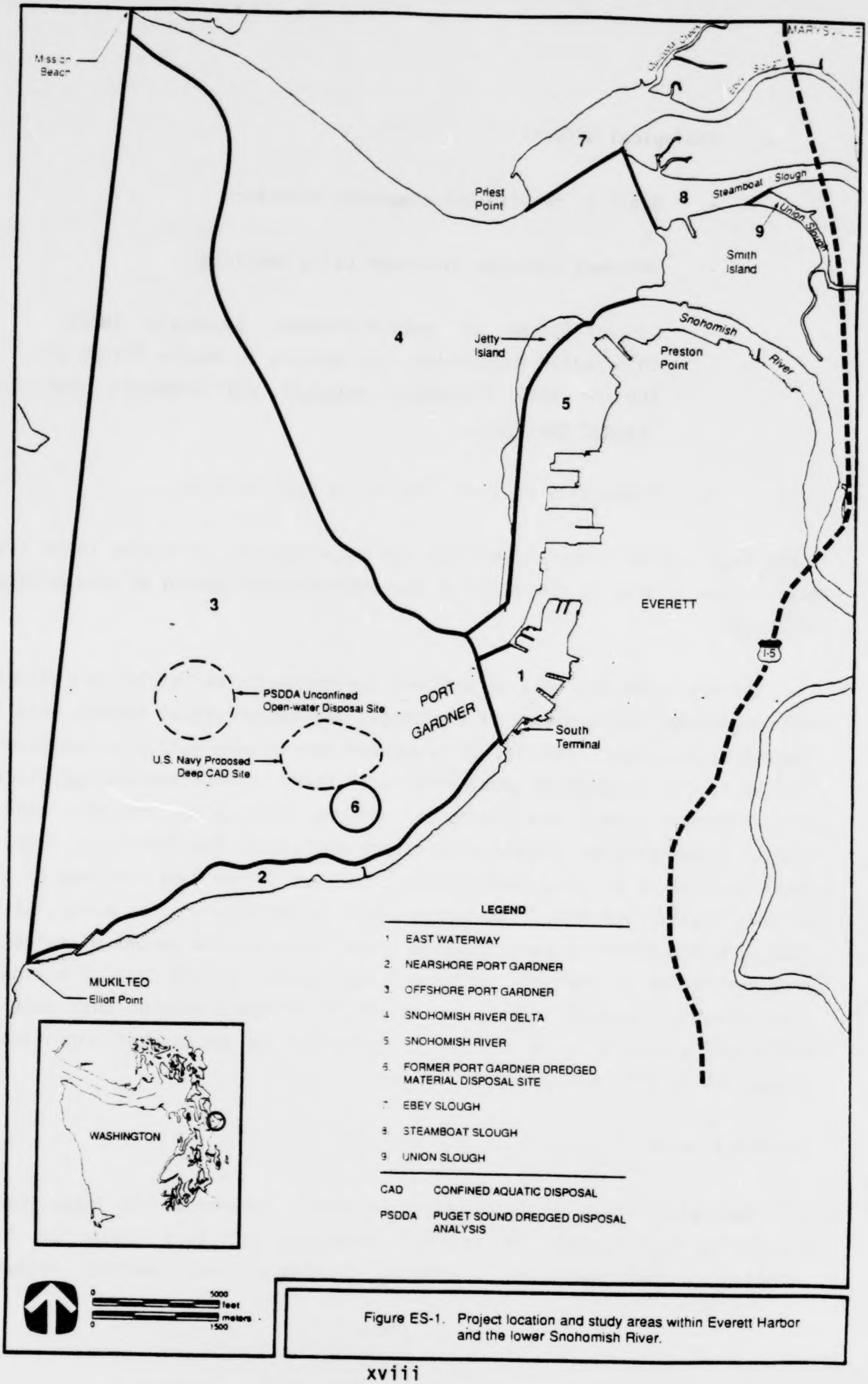

MARYSVILLE
Mission Beach
7
Priest Point
8
Steamboat Slough
Union Slough
9
Smith Island
Jetty Island
Snohomish River
Preston Point
4
5
3
EVERETT
I-5
1
PORT GARDNER
PSDDA Unconfined Open-water Disposal Site
South Terminal
U.S. Navy Proposed Deep CAD Site
6
2
MUKILTEO
Elliott Point
WASHINGTON
LEGEND
1 EAST WATERWAY
2 NEARSHORE PORT GARDNER
3 OFFSHORE PORT GARDNER
4 SNOHOMISH RIVER DELTA
5 SNOHOMISH RIVER
6 FORMER PORT GARDNER DREDGED MATERIAL DISPOSAL SITE
7 EBEY SLOUGH
8 STEAMBOAT SLOUGH
9 UNION SLOUGH
CAD CONFINED AQUATIC DISPOSAL
PSDDA PUGET SOUND DREDGED DISPOSAL ANALYSIS
0
5000
feet
meters
0
1500

Figure ES-1. Project location and study areas within Everett Harbor and the lower Snohomish River.

- **Biological effects**
    - Benthic invertebrate community structure
    - Sediment toxicity bioassays using amphipods
    - Concentrations of polychlorinated biphenyls (PCBs), chlorinated pesticides, and mercury in muscle tissue of English sole (Parophrys vetulus) and Dungeness crab (Cancer magister)
    - Prevalence of liver lesions in English sole.

Tetra Tech (1985a, 1986e) described the rationale for selecting these five major kinds of data to characterize the environmental hazard of contaminated sediments.

The environmental data on sediment contamination and biological effects were organized into a matrix of biological and toxicological indices used to compare study areas. This Action Assessment Matrix uses multiple independent indices termed "elevations above reference" (EAR) to indicate the magnitudes of contaminant levels and biological effects relative to reference conditions. A decision to proceed with source evaluation and ranking of problem areas is limited to sites that exceed a minimum action level defined by one or more significant EAR. The action-level guidelines provide a consistent framework for defining toxic problem areas based on the weight of evidence from evaluation of the selected hazard indicators. In the case of a single significantly elevated index, the magnitude of the elevation must provide sufficient evidence of a problem to outweigh the absence of significant elevations in multiple indicators.

REFERENCE AREAS

Reference areas included nine reference embayments in Puget Sound (including Port Susan) for sediment chemistry and Port Susan for fish pathology, bioaccumulation, sediment bioassays, and benthic infauna.

Sediment chemical concentrations in Port Susan generally fell within the range of other Puget Sound reference areas. Port Susan was chosen to represent a relatively uncontaminated bay in east-central Puget Sound with a major riverine input (i.e., the Stillaguamish River). Data collected during this study generally confirmed the adequacy of Port Susan as a reference area. Nevertheless, at Station PS-02 in Port Susan, an observation of 29 percent mean mortality of amphipods suggested that sediments at this site were toxic to amphipods based on the criterion of ≥25 percent mortality proposed by Mearns et al. (1986). Station PS-02 was therefore excluded from the reference area data set used for statistical comparisons with sediments from Everett Harbor.

SEDIMENT CHEMISTRY

Sediment samples from 60 subtidal and intertidal stations (Figure ES-2) were analyzed for over 140 metals and organic compounds as well as conventional variables. The East Waterway was clearly the most contaminated of all study areas. The highest concentrations of virtually all chemicals measured in the study occurred at stations in the East Waterway (e.g., Stations EW-01, EW-04, EW-07, EW-13, and EW-14, all along the east shore). More moderate contamination in terms of concentrations and complexity of contaminant assemblages was observed in offshore and nearshore Port Gardner study areas (i.e., Areas OG and NG) and at other relatively isolated stations (e.g., Station SR-05 in the Snohomish River).

Organic compounds were much more widely distributed at elevated concentrations than metals. Among the organic compounds with the highest detection frequencies and reported at the highest concentrations were 4-methylphenol [maximum concentration = 98,000 ug/kg dry weight (DW); EAR=7,500], certain resin acids [dehydroabietic acid (maximum concentration = 83,000 ug/kg DW; EAR=1,300) and abietic acid (maximum concentration = 98,000 ug/kg DW; EAR=650)], polycyclic aromatic hydrocarbons (PAH) (naphthalene in particular; maximum concentration = 17,000 ug/kg DW; EAR=3,000), and several tentatively identified organic (TIO) compounds (most notably, a diterpenoid hydrocarbon thought to be dehydroabietane; maximum concentration = 23,000; EAR>1,000). Other organic compounds occurred at high concen-

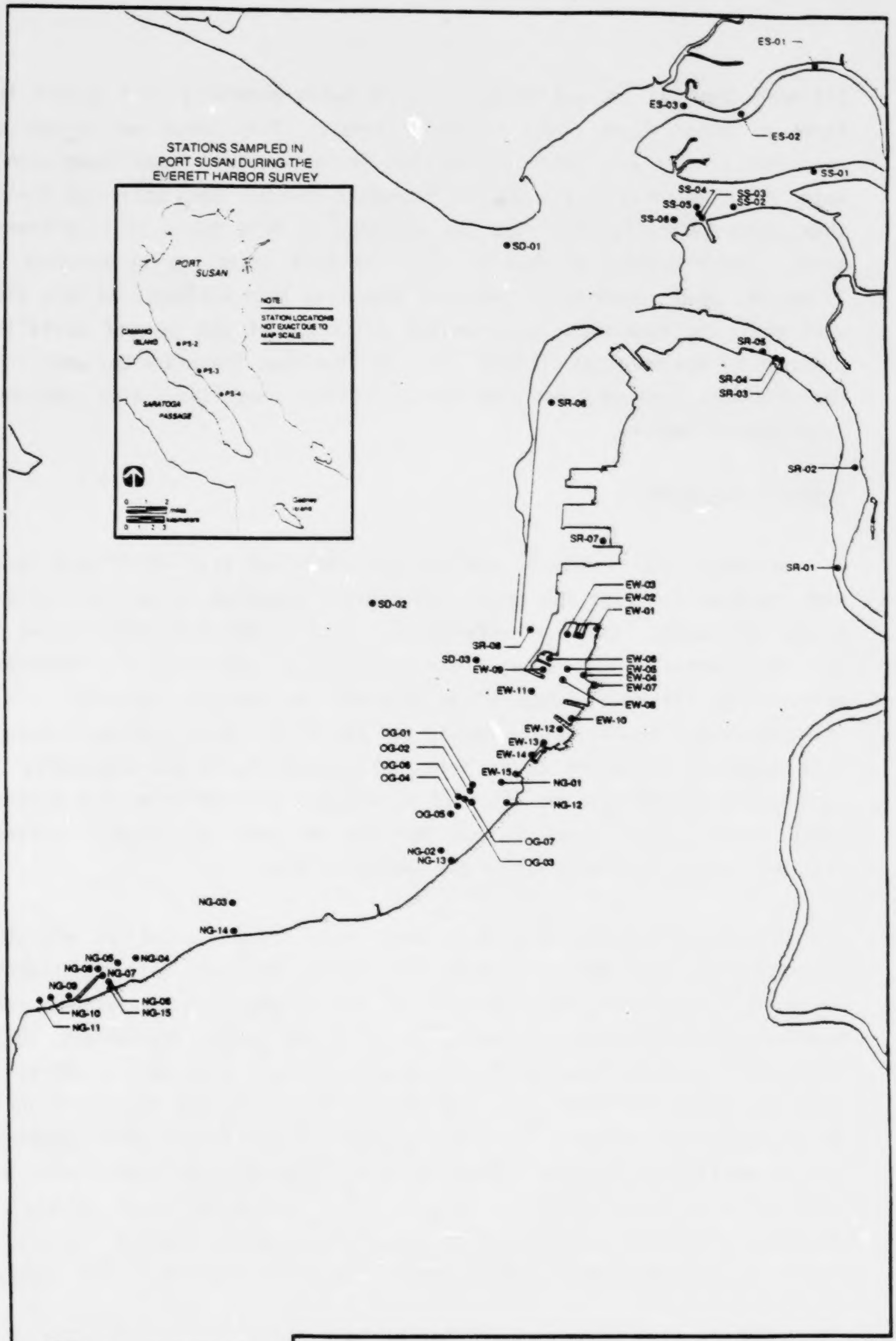

ES-01
ES-03
ES-02
SS-01
SS-04
SS-03
SS-05
SS-02
SS-06
SD-01
STATIONS SAMPLED IN PORT SUSAN DURING THE EVERETT HARBOR SURVEY
PORT SUSAN
NOTE
STATION LOCATIONS NOT EXACT DUE TO MAP SCALE
CAMANO ISLAND
PS-2
PS-3
PS-4
SARATOGA PASSAGE
Gedney Island
0 1 2 miles
0 1 2 3 kilometers
SR-05
SR-04
SR-03
SR-06
SR-02
SR-07
SR-01
EW-03
EW-02
EW-01
SD-02
SR-08
SD-03
EW-09
EW-06
EW-05
EW-04
EW-07
EW-11
EW-08
EW-10
EW-12
EW-13
EW-14
EW-15
OG-01
OG-02
OG-06
OG-04
NG-01
NG-12
OG-05
OG-07
OG-03
NG-02
NG-13
NG-03
NG-14
NG-05
NG-04
NG-06
NG-07
NG-09
NG-08
NG-15
NG-10
NG-11
0 5000 feet
0 1500 meters

Figure ES-2. Locations of sampling stations for sediment chemistry, amphipod bioassay, and benthic macroinvertebrates.

trations at relatively isolated stations (e.g., PCBs; maximum concentration = 9,600 ug/kg DW; EAR=1,600). All of the compounds mentioned above occurred at maximum concentrations along the east shore of the East Waterway. Metals concentrations were highly elevated at a single station in the study (Station EW-14 in the East Waterway), particularly for zinc (5,910 mg/kg DW; EAR=310), copper (1,010 mg/kg DW; EAR=160), and arsenic (684 mg/kg DW; EAR=200). Outside the East Waterway, 4-methylphenol was most elevated over the widest area of any measured chemical.

Historical sediment chemistry data generally supported the findings of the present study, although considerable spatial heterogeneity was apparent for high molecular weight PAH (HPAH) and PCBs in the East Waterway. Notably, available historical studies did not provide data for the organic compounds found at the highest concentrations in the present study (especially 4-methylphenol, dehydroabietic acid, and abietic acid) or for distinctive geochemical tracers of the pulp industry observed in the present study (especially chlorinated derivatives of compounds occurring in coniferous woods, such as chlorinated resin acids and chlorinated guaiacols).

BIOACCUMULATION

Chemical analyses for PCBs, selected chlorinated pesticides, and mercury were performed on muscle tissue samples from 55 individual English sole and 13 composite samples of Dungeness crab from 11 trawl stations, including the Port Susan reference area. For both Dungeness crabs and English sole, none of the 12 pesticides measured were detected in edible muscle tissue from the Everett Harbor study area. Mercury concentrations in edible muscle tissue from Dungeness crabs and English sole from the Everett Harbor study area were similar to, or less than, mercury levels in organisms from the Port Susan reference area. Interpretation of PCB data was limited by low analytical recoveries. Measured PCB levels were generally higher in Dungeness crabs and English sole from the Mukilteo area, the Snohomish River, and the East Waterway than in the Port Susan reference area. However, the maximum theoretical concentrations of PCBs (after adjustment for surrogate recoveries) in crab and fish samples were not elevated substantially above the reference area levels (i.e., maximum EAR of 3.7) and were low when compared to other urban embayments in Puget Sound.

SEDIMENT TOXICITY BIOASSAYS

Sediments from 4 of the 29 Everett Harbor stations tested displayed significant toxicities ($P<0.001$) in the amphipod bioassay when compared with the Port Susan reference area. Sediment grain-size composition did not account for the observed significant toxic effects on amphipods. The most toxic area in Everett Harbor was the East Waterway (mean amphipod mortality = 63 percent; range among stations = 13-100 percent). Total (100 percent) mortality was observed at Station EW-01 near the pulp mill discharge at the head of the East Waterway and at Station NG-04 near the defense fuel storage depot at Mukilteo. The mean mortality of amphipods exposed to sediments from stations throughout the remainder of the study area was generally low (<30 percent mortality), except at Stations NG-06 (43 percent), OG-03 (58 percent), and SR-07 (33 percent).

BENTHIC MACROINVERTEBRATE COMMUNITIES

Benthic macroinvertebrate samples from 16 stations in Everett Harbor and three stations in Port Susan were collected, and specimens were identified to the lowest possible taxonomic level and enumerated. Five stations in Everett Harbor exhibited no significant depressions ($P\leq0.001$) in the abundances of the four major taxa selected for problem area identification (i.e., polychaetes, pelecypods, gastropods, and total crustaceans). Seven stations exhibited one depression, one station exhibited two depressions, and three stations exhibited three depressions. Pelecypods and polychaetes appeared to be the most sensitive indicators among the major taxonomic groups in this study.

The most impacted stations in Everett Harbor were Stations EW-01, EW-07 (East Waterway), SD-01 (Snohomish River Delta), and SR-07 (Snohomish River) based on depressions of major taxa abundance. Species level data suggested that impacts at Station SD-01 may have been caused by extreme physical conditions (see **Results, Benthic Macroinvertebrates**). Species level data also identified East Waterway Stations EW-04 and EW-10 as being greatly impacted.

The lowest numbers of taxa occurred at Stations EW-01, EW-04, EW-07, SD-01, and SR-07 all of which exhibited two or more significant depressions ($P \leq 0.001$) in the abundances of major taxa, except Station EW-04, where only pelecypods were depressed. A normal classification analysis of the species-level data generated station groups that confirmed the identification of problem areas based on the numbers of significantly depressed abundances ($P \leq 0.001$) recorded among the stations for major taxa.

FISH PATHOLOGY

Three major kinds of hepatic lesions (neoplasms, foci of cellular alteration, and megalocytic hepatosis) found in livers of English sole were used to characterize environmental conditions at 10 transect stations in the study area relative to the Port Susan reference area. Although the exact causes of these lesions are unknown, previous studies have demonstrated correlations between high lesion prevalences and toxic contamination of sediments. The prevalences of each of the three lesions were not elevated significantly ($P \leq 0.001$) at any of 10 Everett Harbor transects relative to the reference area. Nevertheless, the magnitudes of the lesion prevalences at many stations in Everett Harbor were greater than those in Port Susan. The spatial distributions of the three kinds of hepatic lesions indicated that most abnormalities were confined to the shoreline between the East Waterway and Mukilteo. Prevalences of neoplasms and foci of cellular alteration were correlated positively ($P \leq 0.05$) with fish age. The prevalence of megalocytic hepatosis was higher ($P \leq 0.05$) in males than in females.

CONTAMINANT, TOXICITY, AND BIOLOGICAL EFFECTS RELATIONSHIPS

Biological effects as measured by the amphipod toxicity bioassay and significant reductions in abundances of benthic infauna taxa were generally associated with higher concentrations of contaminants in sediments. Scatterplots of biological effects vs. concentrations of selected physical/chemical variables were examined. An apparent threshold in the biological response was found for several taxa in relation to specific concentrations of each of the following chemicals or chemical groups: low molecular weight PAH (LPAH) (a sum of six aromatic compounds with two to three rings), HPAH (a sum of 10 aromatic compounds with four to six rings), naphthalene, 4-methylphenol, retene, phenol, and sulfides. For the other organic compounds evaluated, the number of stations with detected values was too small or the distribution of the data was too skewed to show a strong association with the abundances of benthic taxa. Amphipod mortality was generally high at higher concentrations of 4-methylphenol, retene, total organic carbon (TOC), chlorinated phenols, resin acids, and sulfides, but was not clearly related to the other chemical variables evaluated.

Biological effects generally decreased along a spatial gradient from the head of the East Waterway (Station EW-01) to outside the mouth of the waterway (Stations NG-01 and NG-02 near Pigeon Creeks 1 and 2). Although the specific chemical or suite of chemicals responsible for biological effects probably varies among stations, the major biological impacts observed at Stations EW-01, EW-04, and EW-07 are probably related to chemicals associated with pulp mill discharges. The observed spatial gradient is probably not representative of fine-scale spatial patterns, since chemical contamination is more complex along a similar transect when other stations with chemistry data (but no biological data) are considered.

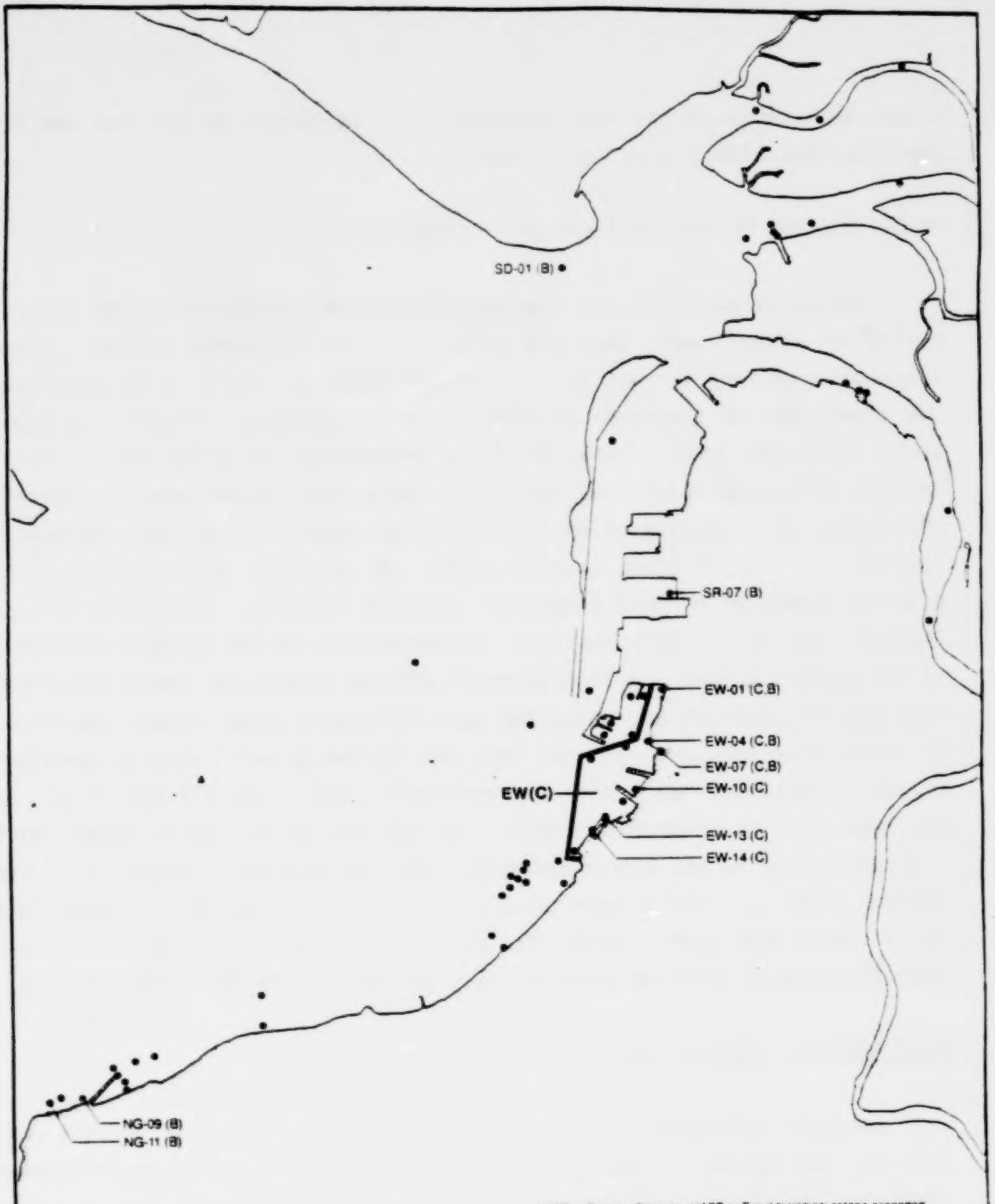
The abundances of most benthic taxa evaluated were not clearly correlated with amphipod mortality. Nevertheless, the total abundance of indigenous amphipods was consistently low at stations with ≥50 percent amphipod mortality in the toxicity bioassay. Overall, concordance between statistically significant responses in the toxicity bioassay and depressions of infaunal taxa was not significantly greater than that expected by chance alone. This is not surprising given the wide range and levels of contaminants in the Everett Harbor system and the different endpoints measured by these two indicators (i.e., acute mortality of adults of a single species in the bioassay vs. potentially both acute and chronic effects on all life stages of an assemblage of species in the benthic infaunal indices). High concordance between the bioassay and benthos was found at highly contaminated sites, especially in the East Waterway, but the number of stations was too small to test statistical significance.

PRIORITIZATION OF PROBLEM AREAS AND CONTAMINANTS

Problem areas defined by indices of sediment contamination and adverse biological effects were localized within the Everett Harbor system. Broad areas of nearshore Everett Harbor and the lower Snohomish River displayed low elevations of chemical concentrations in sediments relative to Puget Sound reference areas (nine reference embayments including Port Susan). Because bioaccumulation and pathology were not significantly elevated ($P \leq 0.001$), large-scale problem areas were not identified by these area-wide indicators. On a finer spatial scale, 23 stations were designated as problems based on sediment chemistry, sediment toxicity, or benthic infauna impacts. At 21 of these stations, concentrations of one or more chemicals in sediments exceeded the high apparent effects thresholds (HAET) developed from matched chemical and biological data throughout Puget Sound. Seventeen of these stations were grouped into the following multi-station problems areas: East Waterway, and the nearshore area from Elliott Point in Mukilteo east to Powdermill Gulch. Of the two multi-station areas, East Waterway ranked as the higher priority. Ten stations were identified as the highest priority sites (Figure ES-3). Of these, Stations EW-01, EW-04, and EW-07 scored high (≥50 percent) for both chemical and biological variables. Each of the major problem areas is characterized in the following sections.

East Waterway Problem Area

Sediment contamination in this depositional area is extreme and complex, and appears strongly related to pulp industry discharges, although additional sources may be important for some chemicals. The East Waterway problem area contained the maximum sediment concentration of virtually every chemical measured in this study. Maximum concentrations of different chemicals occurred at different stations: Station EW-01 (chlorinated guaiacols and certain chlorinated phenols); Station EW-04 (certain chlorinated and unchlorinated resin acids, some alkyl-substituted and chlorinated phenols, most TIO compounds, and PCBs; this station had the largest number


SD-01 (B)
SR-07 (B)
EW-01 (C,B)
EW-04 (C,B)
EW-07 (C,B)
EW(C)
EW-10 (C)
EW-13 (C)
EW-14 (C)
NG-09 (B)
NG-11 (B)
0
5000
feet
meters
0
1500

NOTE Problem Stations - HAET or Tier II biological criteria exceeded

Problem Areas - Contain several problem stations. Lines delineating problem areas are estimated boundaries based on available data (including historical data from stations shown in Figures 31-32) and are not highly precise. Stations not exceeding the criteria may exist within problem areas. See Tables 37, 38, and Appendix J for information on AET exceedances at each station.

Problem area EW and the single stations with labels exhibited scores ≥ 50% for chemistry (C), biology (B), or both (C, B). Identification of station SD-01 as a problem site is tentative (see text).

Figure ES-3. Highest priority problem sites.

of exceedances of HAET and 90th percentile concentrations in the study); Station EW-07 (4-methylphenol and naphthalene); Station EW-13 (several unchlorinated resin acids); and Station EW-14 (most individual PAH compounds, benzoic acid, zinc, copper, arsenic, and other metals).

The relationship between pulp industry activities and sediment contamination in the East Waterway was suggested by several lines of chemical evidence, especially distributions of distinctive geochemical tracers (e.g., chlorinated resin acids and chlorinated guaiacols) and related compounds (e.g., unchlorinated resin acids, chlorinated phenols, retene, diterpenoid hydrocarbons). Distributions of other compounds potentially related to the pulp industry (e.g., 4-methylphenol and naphthalene), TOC, and sulfides also suggested that pulp industry activities were a major source of sediment contamination in the East Waterway.

Comparison of sediment concentrations in the East Waterway to other Puget Sound areas of concern is limited by the lack of data for similar compounds in other studies. Nonetheless, the maximum sediment concentration of 4-methylphenol in the East Waterway was almost identical to the maximum concentration reported in the Commencement Bay Remedial Investigation (Tetra Tech 1985a), and the highest concentrations of LPAH, PCBs, and various other chemicals (e.g., zinc, copper, and arsenic) in the East Waterway exceeded the 95th percentile concentrations found in a recent study of the Elliott Bay/lower Duwamish River system (PTI and Tetra Tech 1988).

Significant depressions in the abundances of benthic infaunal taxa were found at all six stations sampled in the East Waterway ($P \leq 0.001$). Abundances of three of the four major taxa analyzed were significantly reduced at Stations EW-01 and EW-07. Significant sediment toxicity to amphipods was found at three of the six stations sampled in the East Waterway (Stations EW-01, EW-04, and EW-07; $P<0.001$). The mean amphipod mortality for all six stations was 2.9 times the mean mortality at the Port Susan stations. Significant sediment toxicity could not be attributed solely to grain-size effects.

Nearshore Port Gardner Problem Area

The nearshore Port Gardner problem area was primarily contaminated with polar organic compounds (i.e., 4-methylphenol, benzoic acid, and to a lesser extent, phenol), although relatively high concentrations of PAH and PCBs were observed in localized areas. Overall, distributions of different problem chemicals were not consistent in this area. Of the problem chemicals in this area, 4-methylphenol most often exceeded HAET. Based upon observed distributions, 4-methylphenol contamination in this area probably derived from undetermined local sources rather than transport from the East Waterway.

In the nearshore Port Gardner problem area, a significant depression in the abundance of benthic taxa was found only at Station NG-04 (Polychaeta; $P \leq 0.001$). Mean mortality in the amphipod bioassay was 100 percent at Station NG-04 ($P \leq 0.001$). For the nearshore Port Gardner problem area as a whole, the mean amphipod mortality was approximately 1.7 times the reference value.

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) and the Washington Department of Ecology initiated the Everett Harbor Toxics Action Program to correct problems associated with toxic contamination of Everett Harbor and the lower Snohomish River (Figure 1). An assessment of chemical contamination and adverse biological effects is provided in this report, including a ranking of problem areas in terms of priority for evaluation of contaminant sources and remedial action. Remedial actions may include, for example, source control designed to reduce emissions of toxic chemicals and cleanup of contaminated sediments. A preliminary evaluation of toxic problem areas (Tetra Tech 1985b) and a review of existing plans for corrective actions (Tetra Tech 1986e) formed the background for this more comprehensive analysis of problem areas. The field surveys described in this report were designed to fill data gaps and to provide a detailed assessment of environmental hazards. By identifying the worst problem areas based on multiple indicators of chemical contamination and bioeffects, this assessment allows resources for pollutant source investigations and remedial actions to be assigned to the highest priority areas.

Development of a remedial action plan requires that the following kinds of questions be answered for areas within the bay/river system:

1. What is the magnitude of sediment contamination?

2. What is the extent of contamination of aquatic organisms?

3. Has the contamination resulted in significant adverse biological effects?

4. Can the contaminant sources be identified?

5. Would remedial action reduce the threat to the environment?

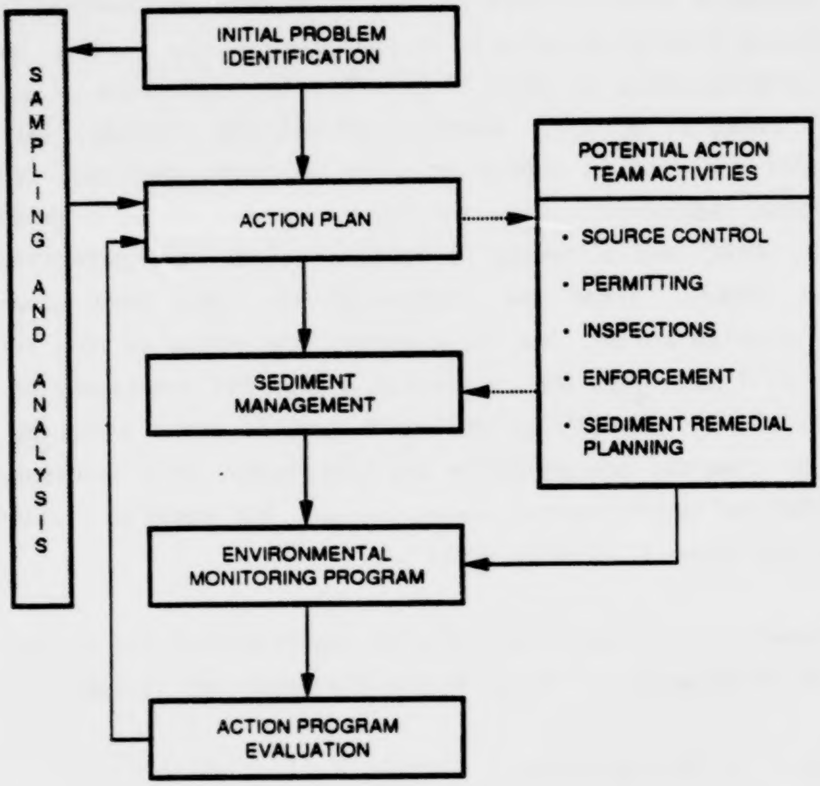

SAMPLING AND ANALYSIS
INITIAL PROBLEM IDENTIFICATION
ACTION PLAN
SEDIMENT MANAGEMENT
ENVIRONMENTAL MONITORING PROGRAM
ACTION PROGRAM EVALUATION
POTENTIAL ACTION TEAM ACTIVITIES
• SOURCE CONTROL
• PERMITTING
• INSPECTIONS
• ENFORCEMENT
• SEDIMENT REMEDIAL PLANNING

Figure 1. Elements of the Everett Harbor Action Program.

Answering Questions 1-5 involves evaluation of data on sources, fates, and effects of contaminants. Data on fates and environmental effects of contaminants are presented in this report. The evaluation of pollutant sources and an updated summary of remedial actions developed by an interagency work group will be presented in separate documents. An assessment of human health risks associated with chemical contamination of fisheries resources in the Everett Harbor system will be performed separately as part of a Puget sound-wide study by EPA.

The evaluation of problem areas as part of the Everett Harbor Toxics Action Program was performed in the context of several other major sediment management programs, i.e.:

- **Puget Sound Dredged Disposal Analysis (PSDDA)**--A multiagency program to develop evaluation procedures for unconfined, open-water disposal of dredged material and to identify disposal sites. A recent baseline survey of the designated disposal site in south-central Port Gardner analyzed sediment chemistry, benthic infauna abundances, sediment toxicity, and bioaccumulation of toxic chemicals by benthic infauna. PSDDA is not intended to identify contaminated problem areas or proposed cleanup actions.

- **U.S. Navy Proposed Homeport for Carrier Battle Group**--Analyses of sediment chemistry, sediment toxicity, benthic infauna, bioaccumulation, and other aquatic indicators were performed to assess material to be dredged from the East Waterway. Similar variables are being measured during the ongoing baseline survey for the proposed U.S. Navy disposal site in Port Gardner.

- **Sediment Standards Element (P-2) of the Puget Sound Water Quality Management Plan**--As directed under the plan developed by the Puget Sound Water Quality Authority, the Washington Department of Ecology is developing standards for adoption by regulation to identify and designate sediments that have observable acute or chronic effects on biological resources or that pose a significant health hazard to humans.

The latter program is designed to identify problem sediments in the environment throughout Puget Sound. Draft sediment quality standards will be proposed by the Washington Department of Ecology in January 1989, with final standards due 30 June 1989. Development of the sediment quality standards will rely partly on previous efforts to develop sediment quality values such as the U.S. EPA urban bay action programs (including the present project), the Commencement Bay Superfund Program, and PSDDA. A review of other plans and activities related to water quality management in Everett Harbor is provided in Tetra Tech (1986e).

The project area and its physical setting are described below. The decision-making approach used to identify and prioritize contamination problems is presented in Chapter 2. The second chapter also provides a summary of the study design and methods used to collect field data. Results of individual study components are presented in Chapter 3, including analyses of: 1) sediment contamination, 2) benthic macroinvertebrates, 3) sediment toxicity as measured by the amphipod bioassay using _Rhepoxynius abronius_, 4) bottomfish ecology, 5) histopathology of English sole (_Parophrys vetulus_) livers, and 6) bioaccumulation of toxic substances in muscle tissue of English sole and Dungeness crab (_Cancer magister_). In Chapter 4, relationships among contamination, toxicity, and biological effects are evaluated. Data for selected indicators are then integrated and evaluated within the decision-making framework to develop a prioritization of problem areas and contaminants.

SITE DESCRIPTION

The Everett Harbor project area includes nearshore areas of Port Gardner, the Snohomish River delta, and the lower Snohomish River estuary (Figure 2). Port Gardner is located east of the northern portion of the main basin of Puget Sound adjacent to Possession Sound. For the purpose of this study, Everett Harbor is defined as the area east of a line joining Elliott

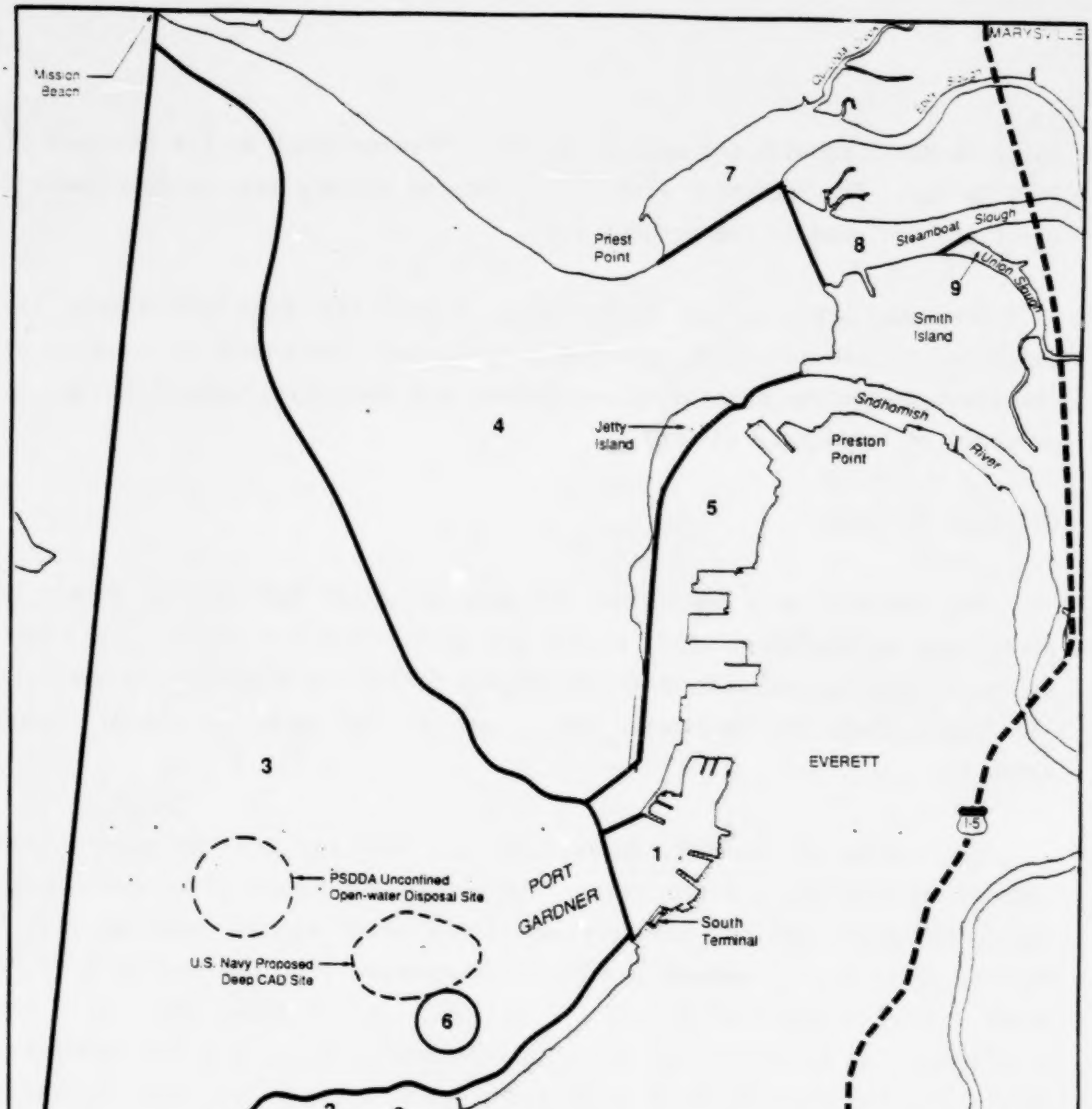

Mission Beach
MARYSVILLE
EBEY SLOUGH
7
Priest Point
8
Steamboat Slough
9
Union Slough
Smith Island
4
Jetty Island
Snohomish River
Preston Point
5
3
EVERETT
I-5
PORT GARDNER
1
PSDDA Unconfined Open-water Disposal Site
U.S. Navy Proposed Deep CAD Site
South Terminal
6
2
MUKILTEO
Elliott Point
WASHINGTON
LEGEND
1 EAST WATERWAY
2 NEARSHORE PORT GARDNER
3 OFFSHORE PORT GARDNER
4 SNOHOMISH RIVER DELTA
5 SNOHOMISH RIVER
6 FORMER PORT GARDNER DREDGED MATERIAL DISPOSAL SITE
7 EBEY SLOUGH
8 STEAMBOAT SLOUGH
9 UNION SLOUGH
CAD CONFINED AQUATIC DISPOSAL
PSDDA PUGET SOUND DREDGED DISPOSAL ANALYSIS
0
5000
feet
meters
0
1500

Figure 2. Project location and study areas within Everett Harbor and the lower Snohomish River.

Point in Mukilteo with the western point of Mission Beach at the entrance of Tulalip Bay. The Snohomish River delta and the estuary east to Interstate 5 (I-5) are included in the project area.

Drainage patterns and study areas within the bay/river system are described in the following sections. Additional background information on the drainage system, physical oceanography, and beneficial uses of the bay is provided in Tetra Tech (1985b).

DRAINAGE PATTERNS

The project area watershed encompasses about 280 km^2 of primarily forest and agricultural lands within the Snohomish River basin. The boundaries of the project watershed are roughly defined by Highway 9 to the east and Casino Road to the south, and extend as far north as the Arlington airport.

The cities of Everett, Marysville, and Mukilteo are the major urban centers within the project area. Surface-water runoff from Everett is collected by a combined sanitary and storm sewer system, treated at the Everett wastewater treatment plant, and discharged into the Snohomish River about 1.2 km downstream of the I-5 bridge. Before 1960, raw sewage was discharged to Port Gardner and the Snohomish River via 14 outfalls. Marysville and Mukilteo each have storm drain systems that are separated from their sewage collection systems. Storm drains within the Marysville area discharge into Quilceda Creek, Allen Creek, and Ebey Slough. Aside from two storm drains within the City of Mukilteo, most of the runoff from Mukilteo and southwest Everett is discharged to southern Port Gardner via numerous small streams. The northern portion of the project watershed comprises largely forested and agricultural lands that drain to Quilceda and Allen Creeks.

The Snohomish River is the largest source of fresh water to Port Gardner and the second largest freshwater inflow to Puget Sound. The Snohomish River basin covers about 4,400 km^2, extending to the crest of the Cascade Mountains. The average annual flow measured near Monroe by the U.S. Geological Survey was about 280 m^3/sec (1963-1983 data) (Williams et al. 1985). The Snohomish River estuary within the project area includes four main branches: Ebey Slough, Steamboat Slough, Union Slough, and the lower Snohomish River channel. The latter carries the major portion of the total river flow. During the dry season, tidal saltwater intrusions have been observed as far upstream as 11 km from Preston Point.

STUDY AREAS

A major objective of this report is to identify spatial patterns in the distribution of contaminants, sediment toxicity, and biological responses in the nearshore region of Everett Harbor and the lower Snohomish River. To facilitate spatial analysis, the nearshore region (i.e., less than approximately 50 m water depth) has been divided into nine smaller areas (see Figure 2) based on geographic features and locations of major sources of contaminants [i.e., storm drains and combined sewer overflows (CSOs)]. Area boundaries and major features are as follows:

1. **East Waterway (EW)**--All of the East Waterway north and east of a line from the Snohomish River mouth black can buoy "3A" to the southernmost boundary of the historical Weyerhaeuser Pulp Mill dock (South Terminal).

2. **South (Nearshore) Port Gardner (NG)**--Shoreline areas (less than or equal to 10 m deep) from Elliott Point (Mukilteo) to the southernmost boundary of the Weyerhaeuser Pulp Mill dock and the area near the defense fuel storage depot at Mukilteo (to 50 m deep).

3. **Offshore Port Gardner (OG)**--All deep water (>10 m) areas of Port Gardner exclusive of other defined areas, including the proposed PSDDA unconfined disposal site.

4. **Snohomish River Delta (SD)**--The area west of a line between the downstream shorelines of Ebey and Smith Islands out to the 10-m depth contour.

5. **Snohomish River** (SR)--The main navigable river channel downstream from the I-5 bridge to the mouth.

6. **Former Port Gardner Disposal Site**--The area formerly designated for the disposal of dredged materials, which will be replaced by the PSDDA site.

7. **Ebey Slough** (ES)--The channel adjacent to the northern boundary of Ebey Island west of I-5 to a line downstream between Priest Point and the western tip of Ebey Island.

8. **Steamboat Slough** (SS)--The channel between Ebey and Smith Islands west of I-5 to a line between the western tip of Ebey Island and the northwestern tip of Smith Island.

9. **Union Slough**--The portion of the slough west and north of I-5.

In this report, the phrase "Everett Harbor system" refers to the entire project area as defined above.

METHODS

Descriptions of the field, laboratory, and data management methods are provided in the following sections. Before these methods are presented, the general approach used to define and rank toxic problem areas is summarized. The decision-making approach provides perspective on the uses of the various kinds of data that were collected and the rationale for specific variables.

DECISION-MAKING FRAMEWORK

The decision-making framework developed for the Everett Harbor Toxics Action Program incorporates a preponderance-of-evidence approach to problem identification. A series of chemical, biological, and toxicological indices are used to relate conditions at sites within the project area to reference conditions in relatively uncontaminated embayments of Puget Sound. Study areas that exhibit high levels of contamination and adverse biological effects receive a ranking of "high priority" for evaluation of pollutant sources and remedial action.

Overview

The decision-making process to evaluate toxic contamination problems is shown in Figure 3. This process focuses regulatory effort and remedial actions on localized areas of severe contamination and biological effects. Major steps in the process to identify and rank toxic chemical problems are as follows:

- Characterize sediment contamination, sediment toxicity, and biological effects

- Quantify relationships among sediment contamination, sediment toxicity, and biological effects

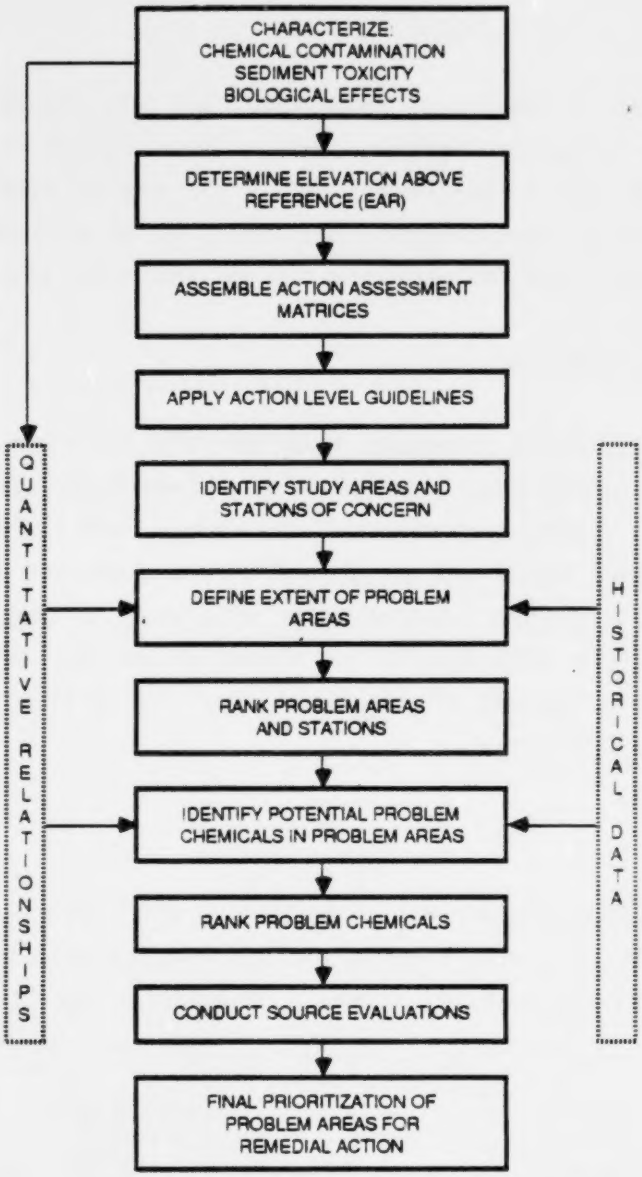

CHARACTERIZE:
CHEMICAL CONTAMINATION
SEDIMENT TOXICITY
BIOLOGICAL EFFECTS
DETERMINE ELEVATION ABOVE REFERENCE (EAR)
ASSEMBLE ACTION ASSESSMENT MATRICES
APPLY ACTION LEVEL GUIDELINES
IDENTIFY STUDY AREAS AND STATIONS OF CONCERN
DEFINE EXTENT OF PROBLEM AREAS
RANK PROBLEM AREAS AND STATIONS
IDENTIFY POTENTIAL PROBLEM CHEMICALS IN PROBLEM AREAS
RANK PROBLEM CHEMICALS
CONDUCT SOURCE EVALUATIONS
FINAL PRIORITIZATION OF PROBLEM AREAS FOR REMEDIAL ACTION
QUANTITATIVE RELATIONSHIPS
HISTORICAL DATA

Figure 3. Decision-making approach for the Everett Harbor Action Program.

- Apply action levels to determine problem areas
- Determine problem chemicals in problem areas
- Define spatial extent of problem areas
- Evaluate sources contributing to problem areas
- Evaluate, prioritize, and recommend problem areas and sources for potential remedial action.

Four major premises underlie this approach. First, it was determined that no single measure of environmental conditions could be used in all cases to define adequately the requirements for potential remedial action. Therefore, recommendations for remedial action investigations are based on several measures of sediment contamination and biological effects. When results of these independent measures corroborate one another (i.e., there is a preponderance of evidence), a problem area is defined. There may be special circumstances where corroboration is not needed because a single indicator provides an exceptional basis for recommending source control or remedial action.

Second, action-level guidelines provide a consistent means for defining problem areas based on significant contamination and effects. These guidelines were developed in consultation with the Everett Harbor Work Group, an interagency task force consisting of representatives from federal, state, and local agencies.

Third, it is assumed that adverse biological effects are linked to environmental conditions that result from source emissions and that these links may be characterized empirically. Relationships between sources and effects will be quantified where possible, for example, by correlations of specific contaminant concentrations and distributions with the occurrence of adverse biological effects. However, proof of specific causal agents is not provided by these studies. Direct cause-effect relationships in the sense of laboratory verification studies are not within the scope of the Everett

Harbor investigation. Nevertheless, analysis of a wide range of contaminants should increase the probability of measuring either the causative substances, or related substances from the same source and with the same distribution in the environment.

Finally, a fourth premise is that the recommended remedial actions may vary from location to location. For example, where biological effects are apparent but contamination originated only from past sources, remedial actions may include removal or capping of contaminated sediments. In contrast, source control may be recommended where contamination originates from an ongoing source even though biological effects may not be apparent. In other cases, both sediment remediation and source control may be recommended. To prevent recontamination of newly cleaned areas, sediment remedial actions should usually be implemented only after major sources have been controlled.

Chemical, Biological, and Toxicological Indices

The primary kinds of data used in the decision-making process are listed below:

- **Sediment Quality**
    - Contaminant concentrations
    - Apparent effects thresholds (AET), relating sediment contamination and predicted biological effects
- **Bioaccumulation**
    - Concentrations of PCBs, chlorinated pesticides, and mercury in muscle tissue of English sole (Parophrys vetulus) and Dungeness crab (Cancer magister)
- **Sediment Toxicity**
    - Amphipod mortality (10-day bioassay)

- **Benthic Infauna**
    - Polychaete abundance
    - Crustacean abundance
    - Pelecypod abundance
    - Gastropod abundance

- **Fish Pathology**
    - Lesion prevalence in livers of English sole.

The rationale for using the five general kinds of data is provided in Tetra Tech (1985a,b). The available Puget Sound AET (Tetra Tech 1986c, 1987) were used as sediment quality values to evaluate chemical data relative to predicted biological effects (see below, **Quantitative Relationships**). Although many other variables were evaluated throughout the decision-making process, those shown above formed the basis for problem identification and priority ranking.

Target Chemicals--

A list of chemical contaminants analyzed for in sediments collected during the Everett Harbor studies is given in Table 1. Most of the substances on this list have at least one of the following two properties: they can bioaccumulate, possibly with adverse biological effects in the food chain if bioaccumulated, or they can produce adverse biological effects even when not bioaccumulated. EPA priority pollutants that may be currently or historically discharged into the study area are included on the list. Compounds not on the EPA list of priority pollutants also have been considered on the basis of their local significance. For example, resin acids and chlorinated phenolic compounds may originate from pulp and paper mills in the project area. In water and effluent bioassays, such compounds may induce a variety of toxic biological responses, from sperm disfunction in sea urchins (Cherr et al. 1987) to mutagenicity (e.g., Kinae et al. 1981) and acute lethality in salmonids (e.g., Leach and Thakore 1973, 1975, 1977). Bioaccumulation of chlorinated phenolic compounds has also been documented (e.g., Landner et al. 1977). Tributyltin (TBT), an antifouling agent, was

TABLE 1. LIST OF CONTAMINANTS AND CONVENTIONAL VARIABLES FOR ANALYSIS IN EVERETT HARBOR PROJECT

- Low Molecular Weight PAH
  - naphthalene
  - acenaphthylene
  - acenaphthene
  - fluorene
  - phenanthrene
  - anthracene

- High Molecular Weight PAH
  - fluoranthene
  - pyrene
  - benz(a)anthracene
  - chrysene
  - benzofluoranthenes (b and k)
  - benzo(a)pyrene
  - indeno(1,2,3-c,d)pyrene
  - dibenzo(a,h)anthracene
  - benzo(g,h,i)perylene

- Total PCBs

- Neutral Halogenated Compounds
  - 1,2-dichlorobenzene
  - 1,3-dichlorobenzene
  - 1,4-dichlorobenzene
  - 1,2,4-trichlorobenzene
  - hexachlorobenzene (HCB)
  - 2-chloronaphthalene
  - hexachlorobutadiene
  - hexachloroethane

- Phthalate Esters
  - dimethyl phthalate
  - diethyl phthalate
  - di-n-butyl phthalate
  - butyl benzyl phthalate
  - bis(2-ethylhexyl)phthalate
  - di-n-octyl phthalate

- Pesticides
  - p,p'-DDE
  - p,p'-DDD
  - p,p'-DDT
  - aldrin
  - chlordane
  - dieldrin
  - endrin
  - endosulfan I
  - endosulfan II
  - endosulfan sulfate
  - endrin ketone
  - heptachlor
  - hepachlor epoxide
  - alpha-HCH
  - beta-HCH
  - delta-HCH
  - gamma-HCH (lindane)
  - methoxychlor
  - toxaphene

- Phenol and Alkyl-Substituted Phenols
  - phenol
  - 2-methylphenol
  - 4-methylphenol
  - 2,4-dimethylphenol
  - 4-chloro-3-methylphenol

- Chlorinated Phenols/Guaiacols
  - 2-chlorophenol
  - 2,4-dichlorophenol
  - 2,4,6-trichlorophenol
  - 2,4,5-trichlorophenol
  - 2,3,4,6-tetrachlorophenol
  - pentachlorophenol
  - 3,4,5-trichloroguaiacol
  - 4,5,6-trichloroguaiacol
  - tetrachloroguaiacol

- Resin Acids
  - abietic acid
  - dehydroabietic acid
  - 12-chlorodehydroabietic acid
  - 14-chlorodehydroabietic acid
  - dichlorodehydroabietic acid
  - isopimaric acid
  - neoabietic acid
  - sandaracopimaric acid

- Nitrogen-Containing Compounds
  - N-nitrosodi-n-propylamine
  - N-nitrosodiphenylamine
  - nitrobenzene
  - 2-nitrophenol
  - 4-nitrophenol

TABLE 1. (Continued)

- 2,4-dinitrophenol
- 4,6-dinitro-2-methylphenol
- 4-chloroaniline
- 2-nitroaniline
- 3-nitroaniline
- 4-nitroaniline
- 2,4-dinitrotoluene
- 2,6-dinitrotoluene
- 3,3'-dichlorobenzidine

Halogenated Ethers
- bis(2-chloroethyl)ether
- bis(2-chloroisopropyl)ether
- bis(2-chloroethoxy)methane
- 4-chlorophenyl phenyl ether
- 4-bromophenyl phenyl ether

Miscellaneous Extractable Compounds[a]
- 2-methylnaphthalene
- dibenzofuran
- benzyl alcohol
- benzoic acid
- isophorone
- hexachlorocyclopentadiene

Volatile Organic Compounds
- acetone
- benzene
- bromodichloromethane
- bromoform
- bromomethane
- 2-butanone
- carbon disulfide
- carbon tetrachloride
- chlorobenzene
- chloroethane
- 2-chloroethylvinyl ether
- chloroform
- chloromethane
- dibromochloromethane
- dichloromethane
- 1,1-dichloroethane
- 1,2-dichloroethane
- 1,1-dichloroethene
- trans-1,2-dichloroethene
- 1,2-dichloropropane
- cis-1,3-dichloropropene
- trans-1,3-dichloropropene
- ethylbenzene
- 4-methyl-2-pentanone
- 2-hexanone
- styrene
- 1,1,2,2-tetrachloroethane
- tetrachloroethene
- 1,1,1-trichloroethane
- 1,1,2-trichloroethane
- trichloroethene
- toluene
- total xylenes
- vinyl acetate
- vinyl chloride

Metals
- antimony
- arsenic
- cadmium
- chromium
- copper
- iron
- lead
- manganese
- mercury
- nickel
- selenium
- silver
- zinc
- tributyltin

Conventional Variables
- total organic carbon
- total solids
- percent fine-grained material
- total nitrogen
- water-soluble sulfides

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[a] Fifteen tentatively identified organic compounds were also analyzed and are listed in the Results section.

analyzed in samples from the Everett marina and Port Susan because of its high toxicity and association with marinas. Several conventional sediment quality variables were measured [e.g., total organic carbon (TOC) content, grain size]. These conventional variables provide a means of comparing areas with different bulk chemical or physical properties. Also, observed biological effects could result from a characteristic of the system unrelated to the selected organic compounds or metals of concern (e.g., the deleterious effects of sediment anoxia on benthic communities).

The target contaminants measured during the Everett Harbor project have the potential to cause observed sediment toxicity or biological effects. However, the ability to identify poorly-understood chemical interactions (e.g., synergism and antagonism) is limited. Although interactive effects may not be distinguishable from other kinds of effects, they may be measured through the use of biological indicators explained below.

Biological Variables--

Selection of individual biological and toxicological variables was based on the following considerations:

- Analysis of several levels of potential biological effects
    - Bioaccumulation at the tissue level
    - Pathology at the tissue level
    - Mortality of amphipods in sediment bioassays
    - Chronic effects on benthic communities
- Use of each variable in past Puget Sound studies
- Documented sensitivity of each variable to contaminants
- Ability to quantify each variable within the resource and time constraints of the program.

Response variables were selected to characterize several important toxic effects in resident organisms of Everett Harbor. Although a study of effects on fish populations was beyond the scope of the current project, a study of effects on individual fishes is possible through an assessment of liver lesion prevalence. Benthic macroinvertebrates were selected because of their sensitivity to sediment contamination, their importance in local trophic relationships, and their ability to establish site-specific response gradients relative to sediment contamination.

The use of Rhepoxynius abronius to determine the acute lethality of field-collected sediments has been documented by numerous authors (e.g., Swartz et al. 1982, 1985; Chapman et al. 1982a,b; Mearns et al. 1986). The use of this amphipod species as an indicator of contaminated areas is supported by its typical absence from natural populations in such areas (Swartz et al. 1982; Comiskey et al. 1984), and by its response to contaminated sediments in laboratory studies (Swartz et al. 1985). Because of potential concerns that uncontaminated fine-grained sediments may induce amphipod mortality, the data collected during the present study were screened to ensure that statistically significant toxicity could not be accounted for by grain-size effects alone.

Elevation Above Reference Indices--

Environmental quality indices were developed to rank areas based on observed contamination and biological effects. The indices have the general form of a ratio between the average value of a variable at a site in the Everett Harbor system and the value of the same variable at a reference site. The ratios are structured so that the value of the index increases as the deviation from reference conditions increases. Thus, each ratio is termed an Elevation Above Reference (EAR) index. For most variables, the measured average value at the study site is divided by the average value at the reference area to obtain the EAR. For benthic infauna, EAR are derived as the inverse ratio of values (i.e., reference divided by Everett Harbor site) to reflect the magnitude of depressed abundances of benthic organisms. Chemical effects on infauna are expected to be manifested as decreases in taxa abundance relative to reference. An increase in the EAR for infauna would therefore reflect a decrease in absolute value of the variable but an increase in adverse effect relative to reference conditions.

It should be noted that these indices were not used in lieu of the original data (e.g., contaminant concentrations), but in addition to these data. The original data were used to identify statistically detectable increases in sediment contamination, sediment toxicity, or biological effects, and to determine quantitative relationships among these variables. The EAR indices were used to reduce large data sets into interpretable numbers that reflect the magnitudes of the different variables among areas.

Action Assessment Matrix

The environmental contamination and effects indices (i.e., EAR) were organized into an Action Assessment Matrix used to compare study areas or stations. A simplified hypothetical example of an Action Assessment Matrix is shown in Table 2. This example matrix is presented to demonstrate how information from multiple indicators can be integrated for an overall evaluation and prioritization of different study areas. For this example, only general indices such as "sediment contamination", or "benthic macroinvertebrates" are used. In the actual application of the approach, multiple indices for specific types of sediment contamination were evaluated, including separate measures for organic compounds and metals (see **Prioritization of Problem Areas and Contaminants**). Similarly, the benthic macroinvertebrates category was replaced by more specific measures of benthic community structure.

Evaluation of information in this format enables the decision-maker to answer the following questions:

- Is there a significant increase in sediment contamination, sediment toxicity, or biological effects at any study site?

- What combination of indicators is significant?

TABLE 2. THEORETICAL EXAMPLE OF ACTION ASSESSMENT MATRIX[a]

Indicator	EAR Values for Study Sites					Reference Value
	A	B	C	D	E	
Sediment contamination	$\boxed{1,300}$	$\boxed{45}$	$\boxed{800}$	$\boxed{75}$	8	1,000 ppb
Toxicity	$\boxed{8.5}$	2.0	$\boxed{10.0}$	$\boxed{4.5}$	2.2	10% mortality
Bioaccumulation	$\boxed{900}$	$\boxed{20}$	$\boxed{1,100}$	$\boxed{200}$	13	10 ppb
Pathology	$\boxed{5.2}$	2.6	$\boxed{8.0}$	$\boxed{2.8}$	2.0	5% prevalence
Benthic macroinvertebrates	$\boxed{4.0}$	1.2	$\boxed{5.0}$	1.3	1.1	60 individuals/m^2

[a] EAR values for indicator variables are shown for Sites A-E. Benthic macroinvertebrate factors represent the reduction in numbers of individuals at the study site relative to the reference site. Factors for all of the other indices represent increases relative to the reference site values shown.

▭ - Indicates indicator value for the specified area is significantly different from reference value.

- What are the relative magnitudes of the elevated indices (i.e., which represent the greatest relative hazard)?

The term "significant" is generally used in this report to mean statistically significant at the 99.9 percent confidence level (alpha = 0.001). With the exception of sediment chemistry, significance of an EAR was based on statistical comparisons of variables between contaminated sites and the reference area. Because replicate data for sediment chemistry were not collected at every station, an alternative criterion for significance was developed. Following the approach used earlier in Commencement Bay and Elliott Bay (Tetra Tech 1985a; PTI Environmental Services (PTI) and Tetra Tech 1988), a significant elevation of a chemical concentration in sediments was defined as exceedance of the maximum concentration of that chemical in all Puget Sound reference areas.

Action-Level Guidelines

The decision to evaluate potential sources of contamination and the need for possible remedial alternatives applies only to those sites that exceed a minimum action level. An "action level" is a level of contamination or effects that defines a problem area. It is assumed that an area requires no action unless at least one of the indicators of contamination, toxicity, or biological effects is significantly elevated above reference levels.

The action levels used to define problem areas in the Everett Harbor system are shown in Table 3. The action-level guidelines are summarized as follows:

- Significant elevation above reference for THREE OR MORE INDICES identifies a problem area requiring evaluation of sources and potential remedial action

- For ANY TWO INDICES showing significant elevations, the decision to proceed with source and remedial action evaluations depends on the actual combination of indices and the degree to which they are site-specific

TABLE 3. ACTION-LEVEL GUIDELINES

Condition Observed	Threshold Required for Action
I. Any **THREE OR MORE** significantly elevated indices[a]	Threshold exceeded, continue with source and remedial action evaluation.
II. **TWO** significantly elevated indices	
1. Sediments contaminated, but below HAET and 90th percentile **PLUS:** Bioaccumulation elevated relative to that at the reference area, **OR** Sediment toxicity with no more than 40% mortality, **OR** Benthic community structure indicates altered assemblage, but less than 80% depression	No immediate action. Recommend site for future monitoring.
2. Sediments contaminated but below HAET and 90th percentile **PLUS** elevated fish pathology	Threshold for source evaluation exceeded if elevated contaminants are considered to be biologically available. If not, recommend site for future monitoring.
III. **SINGLE** significantly elevated index	
1. Sediment contamination	If the magnitude of contamination exceeds the 90th percentile for all study areas or the HAET, proceed with source and remedial action evaluation.
2. Sediment toxicity	Greater than 40% response (mortality).
3. Benthic community structure	80% depression or greater.
4. Fish pathology **OR** bioaccumulation	Insufficient as a sole indicator. Recommend site for future monitoring. Check adjacent areas for significant contamination, toxicity, and/or biological effects.

[a] Combinations of significant indices are from independent data types (i.e., sediment chemistry, bioaccumulation, sediment toxicity, benthic infauna, fish pathology).

Significant indices are defined as follows:

Sediment Chemistry = Chemical concentration at study site exceeds highest value observed at all Puget Sound reference areas.

Sediment Toxicity, Benthic Infauna, Bioaccumulation, and Pathology = Statistically significant difference between study area and reference area ($P<0.001$) at one or more stations within area.

- When only a SINGLE INDEX is significantly elevated, a problem area may be defined when additional criteria are met (i.e., the magnitude of the index is sufficiently above the significance threshold to warrant further evaluation).

Significant sediment toxicity or biological effects may occur in areas without apparent contamination by toxic substances. In such cases, it would be important to evaluate the possibility that the observed conditions result from variables not measured in the field studies. An attempt would be made to distinguish the biological problem area from surrounding areas using chemical characteristics, and to identify sources based on these distinguishing chemical characteristics.

The action-level guideline based on exceedance of the 90th percentile concentration of a chemical in sediments was applied only to chlorinated phenols/guaiacols and resin acids. None of these compounds has an established AET. Application of the 90th percentile guideline to data for other chemicals was considered inappropriate for problem area identification because of availability of AET or relatively narrow concentration ranges observed for a number of chemicals. For example, the 90th percentile values for most metals were below or only slightly elevated above Puget Sound reference conditions. Stations identified as problem areas based only on exceedance of the 90th percentile concentrations for selected chemicals (chlorinated phenols/guaiacols and resin acids) were designated as relatively low-priority problem areas.

Ranking of Problem Areas

Ranking of problem areas was based on a systematic method of assigning scores to sampling sites based on the significance and severity (i.e., EAR) of the various chemical and biological variables. Criteria for scoring problem areas in terms of priority for evaluation of sources and remedial actions are shown in Table 4. Based on these criteria, higher priority would be assigned to an area with many elevated indices (i.e., EAR) than to an area with few. Because the values of the individual indices are assumed

TABLE 4. SUMMARY OF SCORING CRITERIA FOR SEDIMENT CONTAMINATION, TOXICITY, AND BIOLOGICAL EFFECTS INDICATORS

Indicator	Criteria	Score
Metals (one or more)	Concentration not significant	0
	Significant; EAR <10	1
	Significant; EAR 10-<50	2
	Significant; EAR 50-<100	3
	Significant; EAR >100	4
Organic Compounds (one or more)	Concentration not significant	0
	Significant; EAR <10	1
	Significant; EAR 10-<100	2
	Significant; EAR 100-<1,000	3
	Significant; EAR >1,000	4
Toxicity[a]	No significant bioassay response	0
	Amphipod bioassay significant	2
	>40% response in bioassay	4
Macroinvertebrates[b]	No significant depressions	0
	1 significant depression	1
	2 significant depressions	2
	≥3 significant depressions	3
	≥95% depression for ≥1 variable	4
Bioaccumulation (fish muscle)	No significant chemicals	0
	1 significant chemical	1
	2 significant chemicals	2
	≥3 significant chemicals	3
	EAR >50 for ≥1 chemical	4
Fish Pathology[c]	No significant lesion types	0
	1 significant lesion type	1
	2 significant lesion types	2
	≥3 significant lesion types	3
	≥5% prevalence of hepatic neoplasms	4

[a] Toxicity based on amphipod mortality bioassay.

[b] Variables considered were polychaete abundance, crustacean abundance, gastropod abundance, and pelecypod abundance.

[c] Lesions considered were hepatic neoplasms, foci of cellular alteration (preneoplastic nodules), and megalocytic hepatosis.

to represent relative environmental hazards, areas with higher values of the indices are scored higher. Two ranking schemes were used. The first used sediment chemistry indicators only, primarily to characterize the extent and magnitude of contamination. The second used all biological indicators to measure the response to chemical contamination. For ranking based on biological variables, scores for bioaccumulation and pathology were assigned to each subtidal station based on trawl data for the corresponding area in which the station was located. Biological scores for intertidal stations were based only on the results of the amphipod bioassay since other biological variables were not measured at intertidal stations. Scores assigned to a station for individual biological indicators (i.e., bioassay, infauna, bioaccumulation, pathology) were summed to obtain an overall biological-effects score for the station. The total biological-effects score for a station was normalized to the maximum possible score attainable with the available data. This normalization step was necessary to avoid biasing ranks for some study areas towards lower values just because certain data were missing. The maximum possible score for biological effects when all variables were measured was 16 (= sum of 4 for amphipod bioassay, 4 for benthic macroinvertebrates, 4 for bioaccumulation, and 4 for pathology). The range of possible normalized scores for biology was 0-100 (expressed as a percentage). The various areas were then ranked according to the magnitudes of their overall biological-effects scores.

Similarly, scores assigned to the sediment chemistry indicators (i.e., metals and organic compounds) were summed and normalized to the maximum possible score to obtain an overall chemical-contamination score for each station. The maximum possible score for sediment chemistry was 8 (= sum of 4 for metals and 4 for organic compounds). A ranking of problem stations was then developed based on their relative chemical-contamination scores.

Individual stations that exceeded action-level guidelines were grouped into problem areas based on consideration of the following factors:

- Chemical distributions (including data from recent historical studies)

- Nature and proximity of potential sources
- Geographic and hydrographic boundaries.

Historical stations with contaminant concentrations exceeding the highest AET (HAET) were included in the problem areas. Historical stations showing lowest AET (LAET) exceedances were included only if they were contiguous with problem areas defined in the present study.

Total chemical and biological scores for each multi-station problem area were calculated as the averages of the corresponding total scores for individual stations within the area. If the final ranking based on biological effects for a single station or a multi-station problem area differed substantially from that based on sediment chemistry, then the higher-ranking score was given precedence. Thus, some high priority sites were designated strictly on the basis of chemical contamination (i.e., no corresponding biological problems apparent) or strictly on the basis of biological conditions (i.e., no chemical contamination apparent).

Quantitative Relationships

The development of quantitative relationships among possible causative factors, sediment toxicity, and benthic effects identifies threshold concentrations above which changes in the biological indicators are detectable. The basic concept of increased biological effects or sediment toxicity resulting from increased concentrations of a single chemical in sediments is depicted in Figure 4. Four study areas that have statistically elevated effects are shown in the figure. Although there is an elevation in contamination relative to reference conditions at four of the remaining five study areas, there are no statistically detectable increases in the effect indicator above background conditions. Thus, the level of sediment contamination corresponding to Area X (arrow) represents an apparent threshold above which significant effects occur. The contamination of sediments by multiple chemicals may result in a more complex relationship than the example in Figure 4. Such relationships are discussed in detail later (see **Contaminant, Toxicity, and Biological Effects Relationships**).

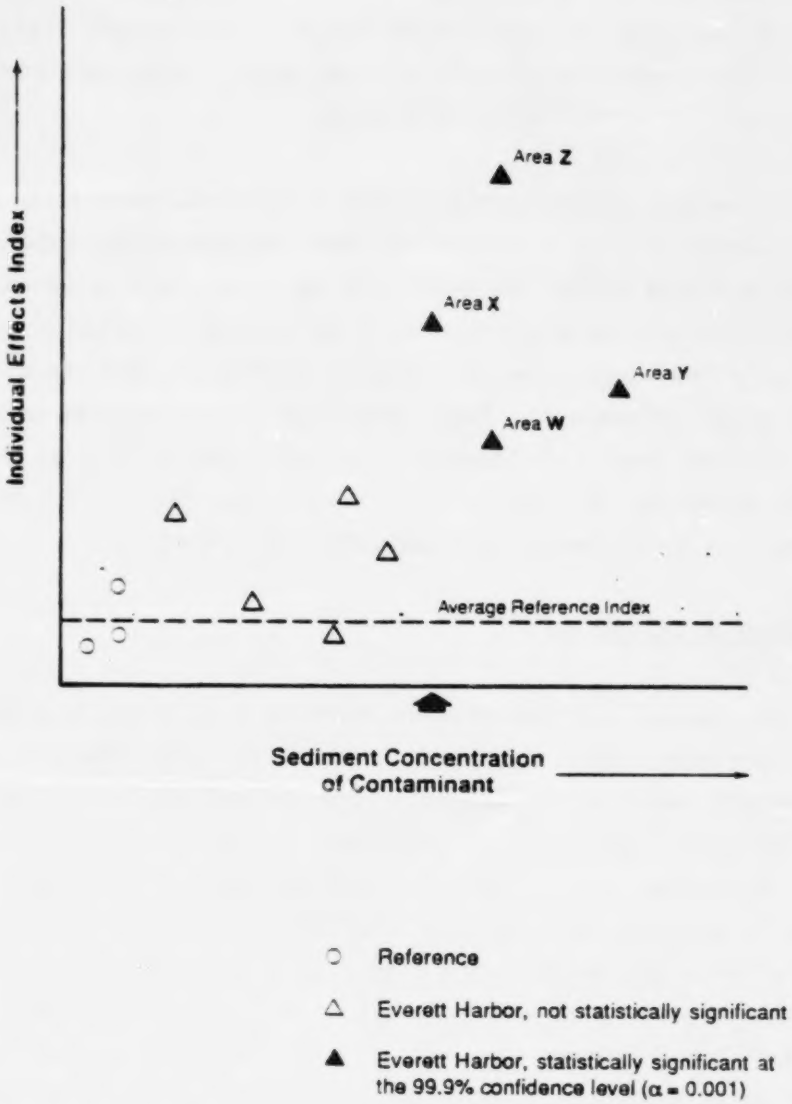


Figure 4. Theoretical example of relationship between sediment contamination and an effects index.

AET have been identified using synoptic chemical and biological data sets from throughout Puget Sound (Tetra Tech 1986c, 1987). Puget Sound AET are used in this study to identify potential problem areas based on chemical data collected in previous studies (e.g., U.S. EPA 1982; U.S. Department of the Navy 1985) where appropriate biological data were unavailable. The concept of AET and the data sets used in deriving AET are explained below. The Everett Harbor data collected during this study are being compiled along with other recent data from Puget Sound into the EPA Sediment Quality Values database (SEDQUAL). This database will be used as part of an ongoing study to update Puget Sound AET.

The focus of the AET approach is to identify concentrations of contaminants that are associated exclusively with sediments having statistically significant biological effects (relative to appropriate reference sediments). Thus, to generate AET values, chemical data are classified according to the absence or presence of significant biological effects to determine concentrations of contaminants above which statistically significant biological effects would always be expected to occur. AET were originally developed to identify problem sediments in the Commencement Bay Nearshore/Tideflats Remedial Investigation (Tetra Tech 1985a). AET have been subsequently revised with an expanded database (200 stations) and their accuracy has been evaluated using biological and chemical data for geographically diverse areas of Puget Sound (Tetra Tech 1986c, 1987). The AET method and accuracy tests based on Puget Sound data are described in detail in those documents.

AET have been established for 64 organic and inorganic toxic chemicals using matched chemical and biological data for several biological indicators and embayments in Puget Sound. Because of patchy biological and chemical conditions in the environment, it was important that chemical analyses be performed on the same or nearly the same sediment that was used in bioassays and benthic infaunal analyses. AET are available for predicting significant effects based on the following biological indicators:

- Depressions in abundances of major taxonomic groups of benthic infauna (i.e., Crustacea, Mollusca, Polychaeta, and total abundance)
- Amphipod mortality bioassay using Rhepoxynius abronius
- Oyster larvae abnormality bioassay using Crassostrea gigas
- Microtox bioluminescence bioassay using Photobacterium phosphoreum.

For each chemical, a separate AET was developed for each biological indicator, resulting in four sets of AET. A list of the different AET generated thus far for Puget Sound is provided in Table 5, along with the LAET and HAET among these four indicators. The derivation of these AET is described in more detail in Tetra Tech (1986c).

The AET method has been shown to be sensitive in correctly predicting impacted stations in Puget Sound, but in doing so the approach also predicts impacts at some stations that do not demonstrate adverse effects [i.e., the approach is not completely efficient in identifying only impacted stations (Tetra Tech 1986c)]. Because the objective for using AET in this study was to identify potential problem chemicals and problem areas (in conjunction with action level guidelines), the ability to correctly predict most impacted stations (sensitivity) is more important than the ability to predict only impacted stations (efficiency).

Spatial Resolution of Effects

Using the Action Assessment Matrix, contamination and effects were analyzed at several levels of spatial resolution (e.g., study areas within the project area or individual stations). Detailed examination of each sampling station was necessary because spatial heterogeneity of sediment contamination was relatively high. Quantitative relationships among sediment contamination, sediment toxicity, and benthic macroinvertebrates

TABLE 5. PUGET SOUND AET (DRY WEIGHT)[a,b]
(ug/kg dry weight for organic compounds; mg/kg dry weight for metals)

Chemical	Amphipod AET[c]	Oyster AET[d]	Benthic AET[e]	Microtox AET[f]	LAET	HAET
Low molecular weight PAH	5,500[g,h,i]	5,200	6,100[i]	5,200	5,200	6,100
naphthalene	2,400[h,i]	2,100	2,100	2,100	2,100	2,400
acenaphthylene	560	>560	640[i]	>560	560	640
acenaphthene	980[h,i]	500	500	500	500	980
fluorene	1,800[h,i]	540	640[i]	540	540	1,800
phenanthrene	5,400[h,i]	1,500	3,200[i]	1,500	1,500	5,400
anthracene	1,900[g,h,i]	960	1,300[i]	960	960	1,900
High molecular weight PAH	38,000[h,i]	17,000	>51,000[i]	12,000	12,000	38,000
fluoranthene	9,800[h,i]	2,500	6,300[i]	1,700	1,700	9,800
pyrene	11,000[h,i]	3,300	>7,300[i]	2,600	2,600	11,000
benz(a)anthracene	3,000[h,i]	1,600	4,500[i]	1,300	1,300	4,500
chrysene	5,000[h,i]	2,800	6,700[i]	1,400	1,400	6,700
benzofluoranthenes	3,700	3,600	8,000[i]	3,200	3,200	8,000
benzo(a)pyrene	2,400	1,600	6,800[i]	1,600	1,600	6,800
indeno(1,2,3-c,d)pyrene	880[h,i]	690	>5,200[i]	600	600	880
dibenzo(a,h)anthracene	510[h,i]	230	1,200[i]	230	230	1,200
benzo(g,h,i)perylene	860[h,i]	720	5,400[i]	670	670	5,400
Total PCBs	2,500[i]	1,100	1,100	130	130	2,500
Total chlorinated benzenes	680[i]	400	400	170	170	680
1,3-dichlorobenzene	>170	>170	>170	>170		
1,4-dichlorobenzene	260	120	120	110	110	260
1,2-dichlorobenzene	>350	50	50	35	35	50
1,2,4-trichlorobenzene	51	64	64	31	31	64
hexachlorobenzene (HCB)	130	230	230	70	70	230
Total phthalates	>5,200[i]	3,400	>70,000[i]	3,300	3,300	3,400
dimethyl phthalate	>700[h,i]	160	160	71	71	160
diethyl phthalate	>1,200[h,i]	>73	200[h,i]	>48	200	200
di-n-butyl phthalate	>5,100	1,400	>5,100	1,400	1,400	1,400
butyl benzyl phthalate	>470	>470	470	63	63	470
bis(2-ethylhexyl)phthalate	>3,100	1,900	1,900	1,900	1,900	1,900
di-n-octyl phthalate	>590[i]	>420	>68,000[i]	--		
Pesticides						
p,p'-DDE	15	--	9	--	9	15
p,p'-DDD	43	--	2	--	2	43
p,p'-DDT	3.9	>6	11[i]	--	3.9	11
Phenols						
phenol	670[h,i]	420	1,200	1,200	420	1,200
2-methylphenol	63	63	>72	>72	63	63
4-methylphenol	1,200	670	670	670	670	1,200
2,4-dimethylphenol	>72[h,i]	29	29	29	29	29
pentachlorophenol	>140	>140	>140	>140		
2-methoxyphenol	930	930	930	930	930	930
Miscellaneous extractables						
hexachlorobutadiene	290	270	270	120	120	290
1-methylphenanthrene	310	370	370	370	310	370
2-methylnaphthalene	670	670	670	670	670	670
biphenyl	260	260	270	270	260	270
dibenzothiophene	240	240	250	250	240	250
dibenzofuran	540	540	540	540	540	540
benzyl alcohol	73	73	73	57	57	73
benzoic acid	>690	650	650	650	650	650
N-nitrosodiphenylamine	220	130	75	40	40	220

TABLE 5. (Continued)

Chemical	Amphipod AET[c]	Oyster AET[d]	Benthic AET[e]	Microtox AET[f]	LAET	HAET
Volatile organics						
tetrachloroethene	>210	140	140	140	140	140
ethylbenzene	>50	37	37	33	33	37
total xylenes	>160	120	120	100	100	120
Metals						
antimony	5.3	26	3.2	26	3.2	26
arsenic	93	700	85	700	85	700
cadmium	6.7	9.6	5.8	9.6	5.8	9.6
chromium	>130	>37	59	27	27	59
copper	800[i]	390	310	390	310	800
lead	700[i]	660	300	530	300	700
mercury	2.1[i]	0.59	0.88	0.41	0.41	2.1
nickel	>120[i]	39	49	28	28	49
silver	>3.7[i]	>0.56	5.2	>0.56	5.2	5.2
zinc	870[i]	1,600	260	1,600	260	1,600

[a] ">" indicates that a definite AET could not be established because the highest concentration occurred at a station without biological effects (hence, it is not clear from available data if biological effects always occur above this concentration, as specified in the definition of AET). For the purposes of problem identification in Elliott Bay, these values were excluded when LAET (low AET) and HAET (high AET) were generated.

[b] The following data sets were used to generate the AET in this table:

1. Battelle (1986)
2. Chan et al. (1985 , unpublished)
3. Comiskey et al. (1984)
4. Osborn et al. (1985)
5. Romberg et al. (1984)
6. Tetra Tech (1985a)
7. Tetra Tech (1986d)
8. Trial and Michaud (1985)
9. U.S. Department of the Navy (1985).

[c] Based on 160 stations.

[d] Based on 56 stations (all from Commencement Bay Remedial Investigation).

[e] Based on 104 stations.

[f] Based on 50 stations (all from Commencement Bay Remedial Investigation).

[g] A higher AET (24,000 ug/kg for low molecular weight PAH and 13,000 ug/kg for anthracene) could be established based on data from an Eagle Harbor station. However, the low molecular weight PAH composition at this station is considered atypical of Puget Sound sediments because of the unusually high relative proportion of anthracene. Thus, the low molecular weight PAH and anthracene AET shown are based on the next highest station in the data set.

[h] The value shown exceeds the Puget Sound AET established in Tetra Tech (1986c) and results from the addition of Eagle Harbor Preliminary Investigation data (Tetra Tech 1986d).

were examined to evaluate small-scale response gradients. AET were used to predict the occurrence of biological problems at stations where chemistry data were available but biological data were not.

Source Evaluation

The objective of source evaluation is to identify sources of contamination, and in turn to guide remedial activities. A limited evaluation of sources is presented in this report based upon the spatial distribution of contamination, the geochemical properties of observed contaminants, and characteristics of known or potential sources. A more complete evaluation of sources will be presented in a separate report (Tetra Tech 1988b).

OVERVIEW OF FIELD STUDY DESIGN

The general design of the field study is described in this section. A summary of data types and samples collected in the Everett Harbor study is shown in Tables 6 and 7. Port Susan was used as a reference area. All of the Everett Harbor and Port Susan data for this study were collected during late August-October 1986. A previous sampling of Port Susan occurred during October 1985 as part of the Elliott Bay Toxics Action Program. Results of the 1986 sampling were compared with the 1985 results and used to evaluate Port Susan as a reference area. Similar methods were used during both years for Port Susan variables discussed in later sections of this report.

Station Locations

The locations of stations sampled during the Everett Harbor project are presented in Figures 5 and 6. Subtidal stations for sampling of sediments were located in shallow water [<50 m water depth] near shore, with the exception of stations located in deep water (>100 m) near the pulp industry wastewater outfall in eastern Port Gardner. Stations for sampling English sole (Parophrys vetulus) and Dungeness crab (Cancer magister) were located near areas sampled for sediments at water depths generally ≤20 m. Coordinates and water depths [corrected to mean lower low water (MLLW)] of all stations are listed in Appendix A.

TABLE 6. SUMMARY OF FIELD STUDY DESIGN

Indicator	Primary Variables	Sample Type	No. Replicates	No. Stations Everett Harbor	Reference[a]
Sediment chemistry	toxic chemicals and conventional variables[b]	composite 0-2 cm[c]	1	57	3
Toxicity bioassay	% mortality	composite 0-2 cm[c]	5	29	3
Benthic infauna	major taxa abundances	0.1-m^2 grab	5	16	3
	species abundances	0.1-m^2 grab	5	16	3
Bioaccumulation	PCBs, pesticides, mercury	Muscle--English sole (>23 cm) and	5	10	1
		Dungeness crab	1		
Fish histopathology	lesion prevalences	English sole liver	1[d]	10	1

[a] The reference area was Carr Inlet for sediment chemistry and Port Susan for the other indicators.

[b] See Tables 1 and 7.

[c] Chemistry and bioassay samples were aliquots of the same composite sample.

[d] 60 fish per sample.

TABLE 7. SUMMARY OF SEDIMENT ANALYSES BY STATION

Station	Semivolatile Organic Compounds[a]	Metals[b]	Conventionals[c]	Volatile Organic Compounds[d]	Resin Acids and Chlorinated Phenolic Compounds	Amphipod Bioassay	Benthic Infauna
ES-01	X	X	X			X	
ES-02	X	X	X	X		X	
ES-03	X	X	X			X	
EW-01	X	X	X	X	X	X	X
EW-02			X	X	X		
EW-03			X	X	X		
EW-04	X	X	X	X	X	X	X
EW-05			X	X	X		
EW-06			X	X	X		
EW-07	X	X	X	X	X	X	X
EW-08			X	X	X		
EW-09			X	X	X		
EW-10	X	X	X			X	X
EW-11	X	X	X		X		
EW-12	X	X	X			X	X
EW-13	X	X	X		X		
EW-14	X	X	X		X	X	X
EW-15	X	X	X		X		
NG-01	X	X	X			X	X
NG-02	X	X	X			X	X
NG-03	X	X	X			X	X
NG-04	X	X	X			X	X
NG-05	X	X	X	X			
NG-06	X	X	X	X		X	X
NG-07	X	X	X				
NG-08	X	X	X				
NG-09	X	X	X				
NG-10	X	X	X			X	X
NG-11	X	X	X				
NG-12[e]	X	X	X			X	
NG-13[e]	X	X	X			X	
NG-14[e]	X	X	X			X	
NG-15[e]	X	X	X			X	
OG-01	X	X	X				
OG-02	X	X	X		X		
OG-03	X	X	X	X	X	X	
OG-04	X	X	X		X		
OG-05	X	X	X				
OG-06	X	X	X		X		
OG-07	X	X	X	X	X		
PS-02	X	X	X	X	X	X	X
PS-03	X	X	X	X	X	X	X
PS-04	X	X	X	X	X	X	X
SD-01	X	X	X		X	X	X
SD-02	X	X	X		X	X	X
SD-03	X	X	X				

TABLE 7. (Continued)

Station	Semivolatile Organic Compounds[a]	Metals[b]	Conventionals[c]	Volatile Organic Compounds[d]	Resin Acids and Chlorinated Phenolic Compounds	Amphipod Bioassay	Benthic Infauna
SR-01	X	X	X			X	
SR-02	X	X	X	X		X	
SR-03	X	X	X		X		
SR-04	X	X	X		X	X	
SR-05	X	X	X		X		
SR-06	X	X	X				
SR-07	X	X	X			X	X
SR-08	X	X	X			X	X
SS-01	X	X	X			X	
SS-02	X	X	X		X		
SS-03	X	X	X	X	X	X	
SS-04	X	X	X		X		
SS-05	X	X	X		X		
SS-06	X	X	X		X		

[a] EPA priority pollutant acid/base/neutral organic compounds, PCBs, and pesticides (see Table 1 for complete list of target chemicals).

[b] EPA priority pollutant metals, except beryllium and thallium. Tributyltin was analyzed at Stations SR-07 and PS-02 only.

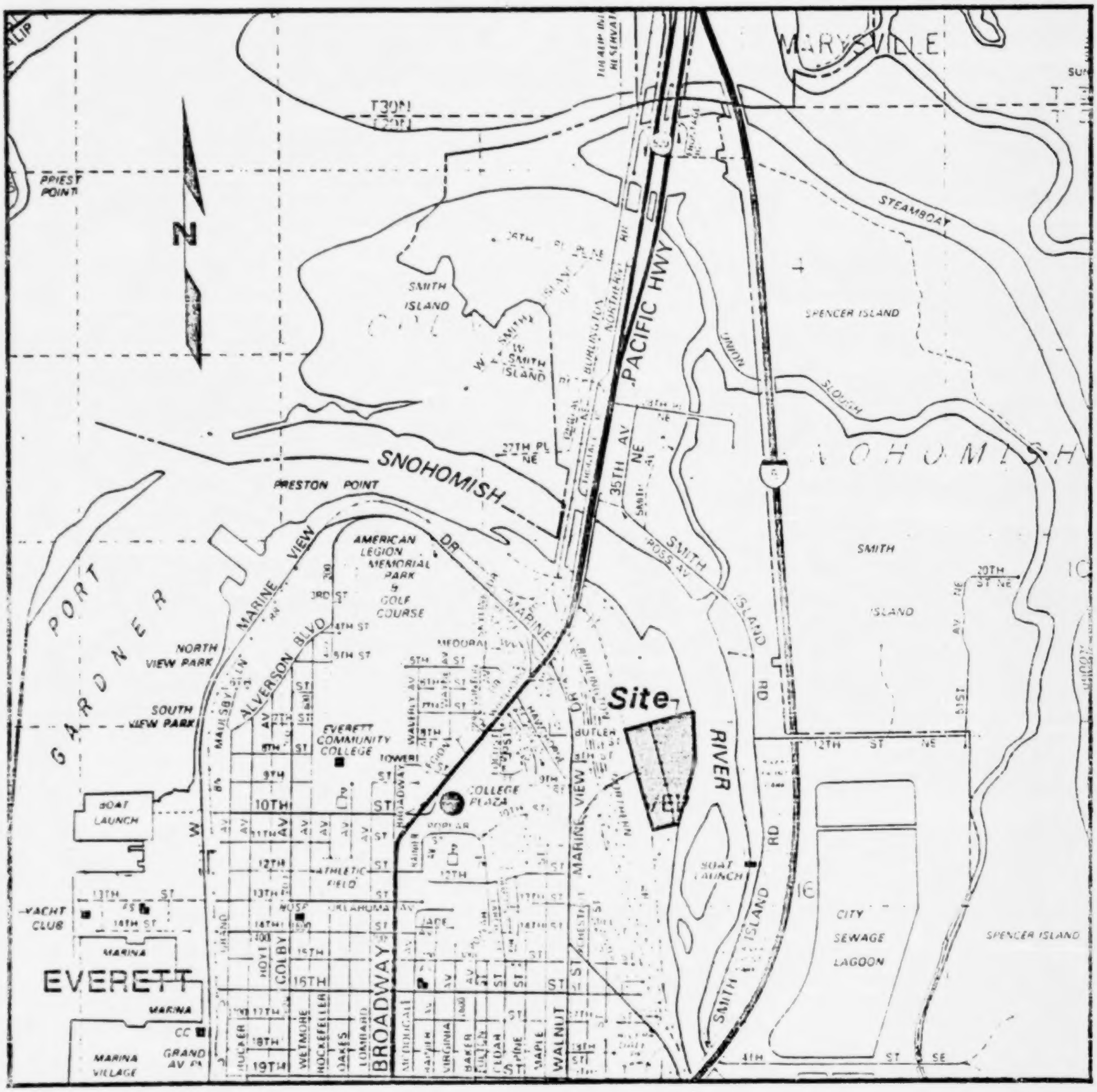
[c] Total organic carbon, total nitrogen, water-soluble sulfides, and grain-size composition.

[d] EPA priority pollutant volatile compounds.

[e] Intertidal station.

Site Vicinity Map

Weyerhaeuser Company, Everett, WA



N
MARYSVILLE
PRIEST POINT
T30N
T29N
STEAMBOAT
SLOUGH
SMITH ISLAND
W. SMITH ISLAND RD
SPENCER ISLAND
BURLINGTON NORTHERN RR
PACIFIC HWY
UNION
SNOHOMISH
PRESTON POINT
PORT GARDNER
MARINE VIEW DR
AMERICAN LEGION MEMORIAL PARK & GOLF COURSE
NORTH VIEW PARK
SOUTH VIEW PARK
ALVERSON BLVD
EVERETT COMMUNITY COLLEGE
COLLEGE PLAZA
ATHLETIC FIELD
Site
RIVER
SMITH ISLAND RD
BOAT LAUNCH
CITY SEWAGE LAGOON
YACHT CLUB
MARINA
EVERETT
MARINA VILLAGE
BROADWAY
WALNUT
12TH ST NE
20TH ST NE

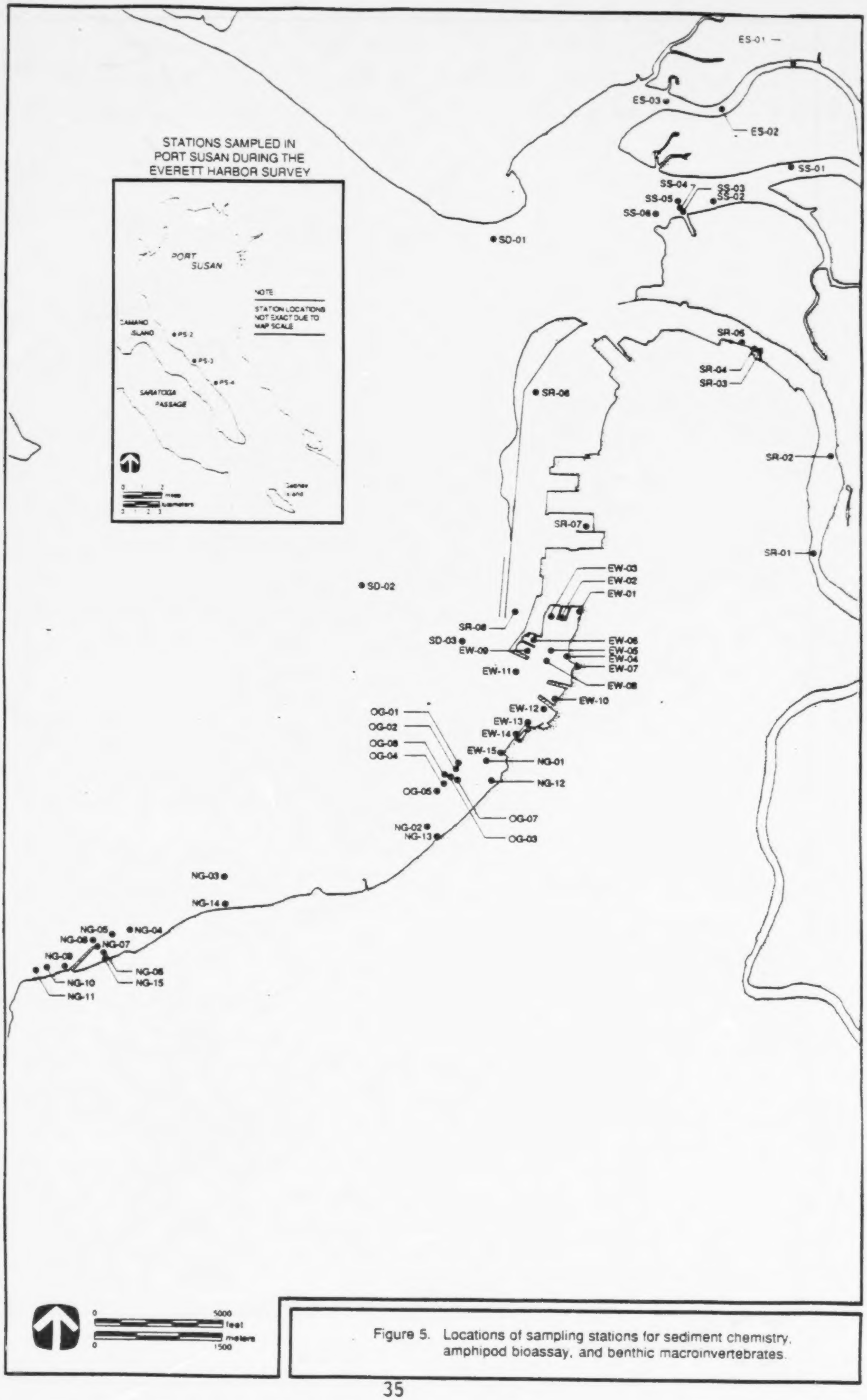
0 1/2 1

Scale in Miles

HARTCROWSER

J-2395-02 4/89

Figure 1


STATIONS SAMPLED IN PORT SUSAN DURING THE EVERETT HARBOR SURVEY
PORT SUSAN
NOTE
STATION LOCATIONS NOT EXACT DUE TO MAP SCALE
CAMANO ISLAND
PS-2
PS-3
PS-4
SARATOGA PASSAGE
Gedney Island
miles
kilometers
ES-01
ES-02
ES-03
SS-01
SS-02
SS-03
SS-04
SS-05
SS-06
SD-01
SD-02
SD-03
SR-01
SR-02
SR-03
SR-04
SR-05
SR-06
SR-07
SR-08
EW-01
EW-02
EW-03
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OG-01
OG-02
OG-03
OG-04
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OG-06
OG-07
NG-01
NG-02
NG-03
NG-04
NG-05
NG-06
NG-07
NG-08
NG-09
NG-10
NG-11
NG-12
NG-13
NG-14
NG-15
0
5000
feet
meters
1500

Figure 5. Locations of sampling stations for sediment chemistry, amphipod bioassay, and benthic macroinvertebrates.

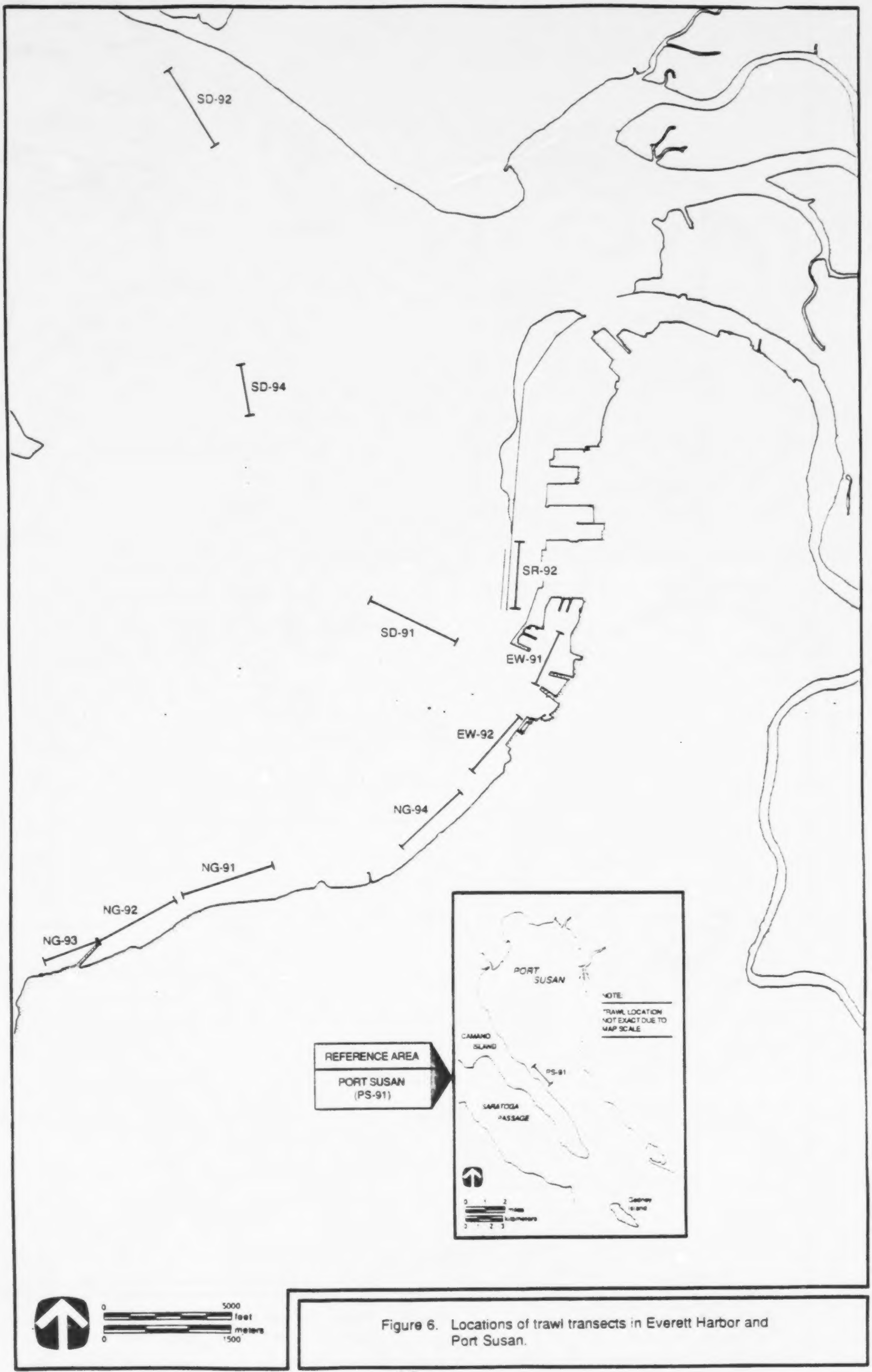
SD-92
SD-94
SR-92
SD-91
EW-91
EW-92
NG-94
NG-91
NG-92
NG-93
REFERENCE AREA
PORT SUSAN
(PS-91)
PORT SUSAN
NOTE:
TRAWL LOCATION NOT EXACT DUE TO MAP SCALE
CAMANO ISLAND
PS-91
SARATOGA PASSAGE
Gedney Island
0 1 2
miles
kilometers
0 1 2 3
0
5000
feet
meters
0
1500

Figure 6. Locations of trawl transects in Everett Harbor and Port Susan.

The rationale for station locations is provided in the sampling and analysis plan for the Everett Harbor Toxics Action Program (Tetra Tech 1986h) and sections below. Briefly, stations were selected to:

- Fill data gaps from previous studies
- Define known areas of contamination more precisely
- Determine large-scale gradients of contamination and bioeffects in relation to known sources
- Detect localized areas of contamination and bioeffects near potential sources.

Note that the triad of sediment chemistry, amphipod bioassay, and benthic infauna was sampled at selected sediment stations in all study areas except Ebey Slough, Steamboat Slough, upstream portions of the lower Snohomish River, and the deepwater outfall site in offshore Port Gardner. Assessment of effects on benthic infauna in these areas would have required extensive sampling of additional reference conditions to match their characteristic salinities or water depths. Such sampling was considered beyond the scope of this project. Moreover, stations in the Snohomish River, Ebey Slough, and Steamboat Slough were not sampled for benthos because of the likelihood of estuarine gradients in community composition that would confound interpretation of the data (Tetra Tech 1986h). Additional cost savings were realized by collecting data on amphipod bioassay mortality and benthic infauna only at selected stations sampled for analysis of sediment chemistry. Stations selected for analysis of the full triad of sediment quality indicators were typically located near known sources of contaminants.

In nearshore areas of Everett Harbor and in the Snohomish River, station locations were determined by line-of-sight fixes on stationary shoreline features. In offshore areas of Everett Harbor and in Port Susan, LORAN C navigational coordinates were recorded for each station. Wherever possible, a variable range marker was used with LORAN C to determine ranges between two reference points, or to determine distances to shore objects. In addition, photographic records of all position alignments and ranges were made at all stations, and depth soundings were recorded. Station positioning methods were sufficiently accurate to define locations within a 15-m radius at most stations and within a 8-m radius at stations that were located in areas where the vessel could be tied to a stationary object. The vessel was anchored at the stations whenever possible during the survey, and station locations were always verified before each sample was collected.

Data Analysis Methods

Chemical Contamination--

The magnitude and spatial extent of sediment contamination was determined by comparisons of chemical concentrations among Everett Harbor study areas and with reference conditions in Carr Inlet and Port Susan. Averaged data from six Carr Inlet stations sampled in 1984 were used whenever possible to calculate EAR for Everett Harbor sediments. Recent Carr Inlet data were used as the basis for calculating EAR for the following reasons:

- The most complete reference data set is available for Carr Inlet, including synoptic data for metals, a wide range of organic compounds, grain size, organic carbon, and other conventional variables

- The lowest detection limits for most substances of concern in Puget Sound embayments are available for Carr Inlet

- Elevations above reference for other urban embayments (e.g., Commencement Bay, Elliott Bay) have been calculated with these data, and therefore, will be directly comparable with the values calculated for this study

- In almost all cases where chemicals were detected in multiple reference areas, the Carr Inlet samples had comparable or lower values and on this basis appear to be reasonably representative of Puget Sound reference conditions.

For chemicals not measured in Carr Inlet (Tetra Tech 1985a), such as resin acids, most tentatively identified organic (TIO) compounds, and chlorinated guaiacols, data from Port Susan were used. Not all TIO compounds were detected in Port Susan. Because detection limits are typically unavailable for TIO compounds, reference concentration of 20 ug/kg dry weight (DW) was assigned as a reasonable detection limit (twice the detection limits for many semivolatile organic compounds in Port Susan) to generate EAR for TIO compounds. EAR values for TIO compounds were used for comparison purposes during data analysis, but were not used during problem area identification and ranking.

Because replicate data for sediment chemistry were not collected at every station, tests for statistically significant differences between Everett Harbor samples and reference area samples could not be conducted. Instead, chemical data from a wide range of Puget Sound reference areas (collected from 1976 to 1986, including the Port Susan data from the present study) were used for determining whether elevations above reference were "significant" (i.e., whether the contamination exceeded all Puget Sound reference conditions). Port Susan data from this study were added to reference data compiled previously (Tetra Tech 1985a). If a chemical was not detected in a reference area sample, detection limits were used to define reference conditions for that chemical. Detection limits greater than 50 ug/kg DW for organic compounds were excluded from the reference area concentration ranges to minimize the bias resulting from less sensitive chemical analyses. Such detection limits observed in other studies were previously excluded from Puget Sound reference area data (Tetra Tech 1985a).

In general, high detection limits were reported infrequently in this study and did not impede data analysis. However, the maximum chemical concentrations for certain compounds (e.g., certain chlorinated benzenes and pesticides) were relatively low and were in some cases exceeded by maximum detection limits. In order to generate 50th percentile (median) and 90th-percentile concentrations that were most representative of chemical conditions in the study area, detection limits greater than 100 ug/kg DW for semivolatile organic compounds or greater than 25 ug/kg DW for single component pesticides were not used in determining percentile concentrations in the study area.

In samples analyzed for chlorinated phenols/guaiacols as well as acid/base/neutral (A/B/N) compounds, data were generated by two different procedures for certain chlorinated phenols (i.e., 2-chlorophenol, 2,4-dichlorophenol, 2,4,5- and 2,4,6-trichlorophenol, and pentachlorophenol). Because detection limits for the dedicated chlorinated phenol analyses were in most cases considerably lower than for the full-scan A/B/N analyses (in extreme cases, by well over two orders of magnitude), only the results for the dedicated analyses were used in data analysis.

For a small proportion of the chlorinated phenol data, detected results for the dedicated analyses were greater than or roughly equal to (within a relative difference of 50 percent) detection limits reported for the full-scan analyses. In these cases, inclusion of the full-scan detection limits would have had virtually no effect on reported data. In three cases, concentrations reported for dedicated analyses were notably greater than full-scan detection limits (i.e., with a relative difference of >>50 percent): 2,4-dichlorophenol at Station EW-01 [320 ug/kg DW (dedicated) vs. U20 ug/kg DW (full-scan)]; 2,4,6-trichlorophenol at Station EW-01 [290 ug/kg DW (dedicated) vs. U100 ug/kg DW (full-scan)]; and pentachlorophenol at Station EW-04 [460 ug/kg DW (dedicated) vs. U200 ug/kg DW (full-scan)]. The full-scan detection limits in these cases may be underestimates [e.g., by not fully accounting for analytical recoveries (6-10 percent recovery for the three cases cited above) or for extraction efficiency (the acetic acid used in dedicated analyses may have enhanced extraction efficiency relative to the full-scan analyses)]. Regardless, favorable quality assurance/quality control (QA/QC) results for the dedicated analyses (Tetra Tech 1988a) and strong correlations among chlorinated phenol concentrations (see **Sediment Chemistry** in **Results** section) support the use of the dedicated results over the full-scan results for these compounds. Preferably, additional sampling will be conducted in the East Waterway to resolve the few discrepancies between reported values for dedicated analyses and detection limits for full-scan analyses.

Pairwise Pearson correlations were performed (using detected data only) to examine covariance in the distribution of selected contaminants. Scatterplots of all correlations cited in text were examined. Based upon relatively strong correlations (e.g., $r>0.8$) among most individual polycyclic aromatic hydrocarbons (PAH), PAH were treated as two compound groups [low molecular weight PAH (LPAH) and high molecular weight PAH (HPAH)] during data analysis. Detection limits were included in these PAH sums.

Biological Effects--

Selected biological variables (i.e., amphipod bioassay, benthic infauna, and liver histopathology) were used to test for statistical differences between study area stations and the reference area (Port Susan). Use of statistical criteria ensured that between-site differences were judged objectively. The statistical design used to test for significant differences between control and test stations adjusted the individual error rate for multiple comparisons. This reduced the probability of a Type I error (i.e., that the null hypothesis being tested was not falsely rejected). The null hypothesis was that the mean value of a variable at the test station was equal to the mean value of that variable at the reference station. This null hypothesis was tested vs. several alternative hypotheses, depending on the biological variable being tested. In environmental studies, control of the Type I error rate becomes increasingly important as the regulatory and legal consequences of incorrectly identifying a difference between mean values become important.

Correction of the error rate for multiple comparisons was necessary because the repetitive use of data collected at a control station results in non-independence among the pairwise comparisons (Winer 1971). If the individual error rate for each comparison is not corrected, then the probability of falsely identifying a significant difference between the test and reference stations increases with the number of pairwise comparisons made. For example, if the selected pairwise significance level is alpha=0.05, and 20 hypotheses are tested (each using the same reference data), then the probability that all of the significant differences identified in the 20 comparisons are correct is $(0.95)^{20}$, or 35.8 percent. This probability decreases as the number of tests increases.

In these studies, the number of pairwise comparisons varied from 11 to 29 among the four biological variables. Selecting an experimentwise error rate of alpha=0.05, and dividing that rate by the number of comparisons would have yielded individual error rates between alpha=0.005 to alpha=0.002. However, a pairwise comparison error rate of alpha=0.001 was selected for all four variables, for three reasons. First, a significance level of alpha=0.001 was sufficiently conservative to assure with 97.1 to 98.9 percent probability that all identified significant differences were true differences. Second, use of the same error rate for tests of all four biological variables ensured comparability among the test results. Third, an error rate of alpha=0.001 was consistent with the pairwise comparison error rate used in the Elliott Bay and Commencement Bay studies.

For benthic macroinvertebrate data, an unpaired two-sample t-test was used to test for a statistically significant difference ($P \leq 0.001$) between each study site (n=5) and the pooled reference site (n=15 for the three stations combined). Before applying the parametric tests, the F_{max} test was used to determine whether the sample variances were homogenous for each paired comparison. Because the variances were heterogeneous in most of the pairwise comparisons, the abundances of infaunal taxa (i.e., polychaetes, crustaceans, pelecypods, and gastropods) used to test for between-site differences were log-transformed $[\log_{10}(x+1)]$. If the variances of the log-transformed data remained heterogeneous between the study site and the reference site (F_{max} test; $P \leq 0.05$), an approximate t-test was applied to the data (Sokal and Rohlf 1981).

Comparisons of benthic infaunal assemblages between stations in Everett Harbor and Port Susan, and other reference areas within Puget Sound are also described. Based on species-level data for all stations within the Everett Harbor study area, faunal similarities among stations were determined using a normal classification analysis. All data were log transformed [$\log_{10}(x+1)$] prior to analysis. The classification analysis involved two steps. First, similarity values were generated for all possible pairs of stations included in the analysis using the Bray-Curtis Similarity Index (see Boesch 1977). This index uses both species composition and the abundances of the individual species to estimate between-site similarity. The group average clustering strategy was then applied to the matrix of similarity values to generate a dendrogram of stations, from which groups of stations (i.e., stations that are most similar in species composition and abundance) were determined.

For the amphipod (Rhepoxynius abronius) bioassay data, a two-sample analysis of variance (ANOVA), which is statistically equivalent to a t-test, was used to test for a significant difference ($P \leq 0.001$) between each study site station (n=5) and the pooled reference stations (n=10 for two stations combined). Station PS-02 was excluded from the reference area data set because of excessive mortality (see **Sediment Bioassays** in **Results** section). Following the approach of Mearns et al. (1986), the data were transformed using an arcsine transformation only when the variances were heterogeneous. Homogeneity of variances was tested using the F_{max} test ($P \leq 0.05$). The mean mortality and 95 percent confidence limits for reference area samples from Port Susan were compared with similar statistics for other reference areas used during previous studies.

There is evidence that the R. abronius bioassay is subject to limited grain-size effects and attempts have been made to quantify and compensate for these effects (DeWitt et al. 1988). The present data were examined using simple linear regression to test for a predictive relationship between amphipod mortality and grain-size (percent fine-grained material).

Lesion prevalence and male proportion (i.e., an index of fish sex ratio) were compared between each transect in Everett Harbor and the Port Susan transect using the G-test of independence ($P \leq 0.001$) with Williams' correction factor (Sokal and Rohlf 1981). Before testing for a difference in lesion prevalence, the age distribution of fish sampled for histopathological analyses was compared between each transect in Everett Harbor and the Port

Susan transect using the Mann-Whitney U-test. When the age distributions were significantly different ($P \leq 0.05$), adjustments were made to the data set for the Everett Harbor trawl site by removing data for individuals of an extreme age class until the age distributions were no longer different. The similarity among the prevalences of all three lesions across all transects was determined using Kendall's coefficient concordance (W). Within Everett Harbor, the proportion of males having each kind of hepatic lesion was compared with the corresponding proportion of females using the G-test of independence with Williams' correction factor. Positive association between the prevalence of each kind of lesion and fish age was tested using Spearman's coefficient of rank correlation (r_s). Length-at-age was compared between fish with and without hepatic lesions using the Mann-Whitney U-test.

Otoliths were available for age determination for 650 of the 660 (98 percent) English sole sampled in Everett Harbor and Port Susan. Ages of the 10 fish not having corresponding otoliths were estimated from age-length keys based on the 650 fish of known age, stratified by sex (Ricker 1975). Once age determinations were made, fish younger than 3 yr old (n=66) were excluded from subsequent analyses. The goal of this study was to focus on individuals ≥3 yr old (i.e., those most likely to be afflicted with serious idiopathic hepatic lesions).

For bioaccumulation, qualitative comparisons of polychlorinated biphenyl (PCB) and mercury concentrations in tissues of English sole and Dungeness crabs were made among stations. Pesticides data were not tested statistically because pesticides were not detected in any tissue samples. No statistical tests were performed to determine among-station differences in contamination of Dungeness crab because replicate samples were not collected at stations other than Station EW-91. Limitations of PCB data due to low analytical recoveries (see below, **Bioaccumulation, Quality Assurance/Quality Control Results**) precluded statistical treatment of PCB data for English sole. Statistical tests were not performed on mercury data for English sole because reference-area concentrations were highest in the study.

SEDIMENT CHEMISTRY

Field Sampling

Full details of the sampling design and techniques are provided in the "Sampling and Analysis Design for Development of Everett Harbor Action Program" (Tetra Tech 1986h) and the "Quality Assurance Project Plan for Field Investigations to Support Development of the Everett Harbor Action Plan" (Tetra Tech 1986f). Field collection procedures followed the recommendations of the Puget Sound Estuary Program (PSEP) (Tetra Tech 1986g).

Sediment samples were collected between 2 and 29 October 1986 using a chain-rigged van Veen grab sampler with a cross-sectional area of 0.1 m^2. Following deployment, the closed grab was retrieved and placed in a sampling tray. The hinged lids of the van Veen sampler were opened to inspect the sample.

Care was taken to ensure recovery of an intact surface sediment layer, with four major criteria used for rejection of a sample:

- Overflowing sediments, with sediment touching the top of the closed cover
- Water leaking from the sides or bottom (i.e., indicating that the interstitial water in the sample was being flushed with overlying seawater), or visible scour of the sediment surface near the edges of the sampler
- Turbid water overlying the sediments
- Insufficient penetration depth.

After the field supervisor determined maximum penetration depth and sample acceptability, qualitative observations were recorded on field log sheets for sediment color, odor, texture, and the presence of recognizable organisms. An HNu photoionization detector was used to monitor all sediment samples for harmful vapors.

When it was determined that the grab triggered incorrectly, that the sample was disturbed, or that some of the sample was lost, a new sample was taken. More than one grab at the same station sometimes was necessary to obtain an acceptable depth of penetration. In medium to coarse sand, a minimum penetration depth of 5 cm was considered acceptable. In fine sand and sandy silt, a penetration depth of 7 cm was the minimum acceptable depth. When attempts to sample a station were unsuccessful, another nearby station was selected and documented. Standardized collection data (i.e., collection date and time, station location, depth, and replicate number) were recorded for each sample.

Once onboard, samples were held in a vertical position by blocks and the overlying water was carefully drained off by an aspirator. Subsamples for volatile organic analyses were taken by placing 1.5-oz glass jars (duplicates) at the undisturbed sediment surface and filling them using a stainless-steel spatula. These sample jars were tightly sealed using Teflon tape, with no headspace remaining. Jars for volatile analysis were filled as tightly as possible, eliminating obvious air pockets. Subsamples for sulfide analysis were immediately removed from the sampler and placed in a tared plastic container with 50 mL of sulfur antioxidant buffer.

The remaining subsamples were taken from a homogenized sample. Each sampling horizon from the upper 2 cm of sediment away from the edge of the van Veen sampler was carefully removed with a stainless steel spatula, transferred to a stainless steel bowl (which was pre-rinsed with site water and methylene chloride), and homogenized by stirring with a stainless steel spoon. Samples were stirred until uniform color and textural homogeneity were observed. Subsamples for metals and semivolatile organic analyses were removed with a stainless steel spoon and placed in precleaned glass jars with polytetrafluoroethylene (PTFE)-lined lids. Subsamples for grain size analysis were placed in polyethylene bags.

Intertidal samples were collected from shore using a stainless steel spatula. Otherwise, intertidal and subtidal sediment samples were processed and analyzed in similar fashion.

Sample handling (including chain-of-custody procedures) and sample storage are addressed in detailed quality assurance reports prepared for this project (Tetra Tech 1988a).

Laboratory Analysis for Metals

The following 11 of the 13 EPA priority pollutant metals were analyzed in 54 sediment samples: antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc. The remaining two priority pollutant metals, beryllium and thallium, were not analyzed because historical data did not suggest that these metals were of concern in the study area. Iron and manganese were also analyzed in 54 samples and TBT was analyzed in two samples. Analyses were performed at Battelle Northwest Marine Research Laboratory in Sequim, Washington.

Samples were prepared by thawing the frozen sediment, and then homogenizing, freeze-drying, and grinding each sample. The sample was then either subjected to a total acid digestion for atomic absorption analysis, or pressed into a pellet for x-ray fluorescence (XRF) analysis. Total acid digestion was performed by combining 1 mL of 4:1 nitric acid:perchloric acid (HNO_3:$HClO_4$) with a 0.200-g sample in a PTFE bomb at 130° C for 4 h. After the sample was cooled, 3 mL of hydrofluoric acid was added and the bomb was heated overnight at 130° C. After cooling, 20 mL of 2.5 percent boric acid (H_3BO_3) was added and the bomb was heated again at 130° C for 8 h. After the weight and volume of the digestate were determined, the solution was analyzed for silver, cadmium, antimony, and selenium by Zeeman graphite furnace atomic absorption (GFAA) using the method of standard addition for calibration. Cadmium and silver were first concentrated into aminopyrolidine dinitrocarbonate (APDC). Mercury was determined on aliquots by cold vapor atomic absorption following preconcentration into APDC. The mercury detector was calibrated with standard solutions.

XRF was used to quantify arsenic, chromium, copper, iron, manganese, nickel, lead, and zinc. Thin film standards (Neilson 1977) were used to calibrate the XRF analyzer. Although the analysis of these metals by XRF differs from routine EPA methods, the PSEP protocols (Tetra Tech 1986g) specify that XRF may be used if accuracy and precision can be demonstrated to the levels specified by the program.

TBT was analyzed by GFAA following extraction of organotin species into methylene chloride, and back extraction of TBT into sodium hydroxide solution (Homer and Dooley 1983).

Laboratory Analysis for Semivolatile Organic Compounds

The methods used for analysis of A/B/N semivolatile organic compounds followed Tetra Tech (1986a). Analyses were performed at Enseco/California Analytical Laboratories (CAL) in West Sacramento, California.

An 80-g homogenized sediment sample was spiked with the stable isotope-labeled analogs of the target compounds (8 ug of base and neutral compounds and 12 ug of acid compounds). The sediment was then Soxhlet-extracted with methylene chloride/methanol (2:1, vol/vol). The resulting extract was subjected to liquid-liquid partitioning with water and was dried by elution through a sodium sulfate column. Elemental sulfur, a common interferant in estuarine and marine sediments, was removed from the extract with metallic mercury. Biological macromolecules were then removed from the extract by gel permeation chromatography. The extract was subjected to reverse phase column chromatography (bonded C_{18} solid phase) to reduce interferences from unresolved paraffinic hydrocarbons prior to capillary gas chromatography/mass spectrometry (GC/MS) analysis for A/B/N compounds using the isotope dilution technique. Compounds without labeled analogs (Table 8) were quantified using the nearest eluting, most chemically similar labeled compound as a recovery standard. All reported concentrations were corrected for recovery using the isotope dilution technique. Recoveries of isotope-labeled standards were determined by the internal standard technique.

TABLE 8. LABELED COMPOUNDS USED WHEN ANALOG NOT AVAILABLE

- d_7-2-methylpyridine
  - aniline

- d_8-naphthalene
  - benzyl alcohol
  - 2-methylphenol
  - 4-methylphenol
  - N-nitrosodi-n-propylamine
  - bis(2-chloroethoxy)methane
  - benzoic acid
  - 4-chloroaniline
  - 2-methylnaphthalene

- d_{10}-acenaphthene
  - 2-nitroaniline
  - 3-nitroaniline
  - 4-nitroaniline
  - dibenzofuran

- d_{10}-phenanthrene
  - 4-bromophenyl phenyl ether

- d_{12}-benz(a)anthracene
  - butyl benzyl phthalate

- d_{12}-benzo(g,h,i)perylene
  - indeno(1,2,3-cd)pyrene
  - dibenzo(a,h)anthracene

The first batch of samples extracted by the laboratory yielded consistently lower, but acceptable recoveries of the isotope-labeled compounds than the subsequent batches. The laboratory was unable to determine the cause for this systematic phenomenon.

Lower limits of detection (LLD) were determined according to guidelines specified in Tetra Tech (1986a). Based on the complexity of the extracts, three levels of LLD were established. The data quality objective of 10 ug/kg DW was met for the "cleaner" samples.

Tentatively Identified Organic Compounds--

TIO compounds were searched for in all extracts of Everett Harbor sediments analyzed for A/B/N compounds by GC/MS. Analyses were performed at Tetra Tech on a stand-alone Finnigan GC/MS data system with data stored on 9-track magnetic tapes generated at CAL. The following procedure was used to acquire data for TIO compounds:

- Preliminary, intensive searches were conducted on roughly 25 percent of the samples. Most samples were chosen from the most contaminated areas (e.g., the East Waterway), but representatives of all study areas were examined. Fifteen chemicals that occurred most frequently and at the highest concentrations were selected for routine searches in all samples.

- Routine searches for the 15 selected TIO compounds were performed in all samples and in two method blanks.

- Concentrations were estimated based on d_{10}-phenanthrene (a standard spiked in the sample at a known concentration) and response factors that accounted for the variations in fragmentation between d_{10}-phenanthrene and the TIO compounds. TIO compound concentrations were recovery-corrected based upon d_{10}-phenanthrene. It is unlikely that d_{10}-phenanthrene recovery was applicable across the chemically diverse range of

TIO compounds. For compounds similar to phenanthrene (e.g., retene), recoveries were likely similar to d_{10}-phenanthrene. For more polar compounds such as fatty acids, the recovery correction was likely an underestimate. Thus, recovery corrections were "conservative" overall. All detected values were qualified as estimates and assigned an "E" qualifier.

- Undetected TIO compounds were reported as U (without a detection limit). Sufficient information was not available to determine detection limits.

- Several compounds were found at low levels in blanks. Any compound found in a sample at a level less than five times the highest concentration found in any blank was reported as a B (with no accompanying value).

Laboratory Analysis for PCBs

The extraction and cleanup procedures were performed according to Tetra Tech (1986a) with the following notable exceptions:

- 40 g of sediment were extracted and none of the extract was split for A/B/N analysis

- No isotopically labeled A/B/N compounds were added [the isotope dilution technique described in Tetra Tech (1986a) applies only to A/B/N compounds].

Analyses of PCBs in extracts were performed at CAL by two instrumental methods: gas chromatography/electron capture detection (GC/ECD) and GC/MS with limited mass scanning. Only GC/ECD analyses were originally planned for these analyses. However, review of the data generated by GC/ECD indicated that sample interferences detracted from the reliability of qualitative and quantitative results. GC/ECD results for two matrix spike samples and two sediment standard reference materials were low (10 to 55 percent recovery for the matrix spikes and 9 to 32 percent of accepted values for the reference materials), whereas recoveries for spiked blanks (without sample interferences) were considerably better (70 to 80 percent). To address the apparent problems with interferences, samples with reported values greater than 50 ug/kg (DW) or detection limits greater than 50 ug/kg (DW) were re-analyzed by GC/MS with limited mass scanning. Two samples had reported GC/ECD results of less than 50 ug/kg (Samples NG-08 and SD-03) and thus did not require re-analysis by GC/MS. All other positive PCB results in the database were generated by GC/MS.

GC/ECD Analysis--

The instrumental and quantification methods described in Tetra Tech (1986a) were followed with several exceptions. Most notably, external standard quantification was used rather than the recommended internal standard method, peak heights were used rather than peak areas, and a single-point calibration was used rather than a five-point calibration. A peak-by-peak, modified Webb-McCall technique was used to quantify PCBs. Relative response factors for 25 resolved peaks in a PCB standard containing Aroclors 1242, 1254, and 1260 (the range of congeners expected in environmental samples) were determined by measuring the individual peak concentrations by GC/MS and then using dilutions of the same standard for initial and ongoing GC/ECD calibrations. Dual capillary column analyses were performed with a 30-m DB-5 column (for quantification) and a 30-m DB-1701 column (for confirmation) (J & W Scientific).

GC/MS Analyses--

GC/MS analyses were performed with a 30-m DB-5 fused silica capillary column (J & W Scientific); the GC oven was temperature-programmed from 50° C (held 1 min) to 320° C at 6° C/min. The internal standard was d_{10}-phenanthrene. The following ions were monitored for each chlorination level: m/z 222, 224 (dichloro-); m/z 256, 258 (trichloro-); m/z 292, 290, 294, 222 (tetrachloro-); m/z 326, 328, 256 (pentachloro-); m/z 360, 362, 292 (hexachloro-); m/z 394, 396, 398, 326 (heptachloro-); and m/z 430, 428, 360 (octachloro-). Thus, for more chlorinated congener groups that might coelute with less chlorinated congeners, (M-70)+ ions were used to ensure that peaks were not double-counted or misclassified.

The congener standard containing representative compounds differed slightly from the recommendations of Tetra Tech (1986a) and U.S. EPA Method 680: 2,4-dichlorobiphenyl was used rather than 2,3-dichlorobiphenyl; 2,4,6-trichlorobiphenyl was used rather than 2,4,5-trichlorobiphenyl; 2,2',3,4',5,6'-hexachlorobiphenyl was used rather than 2,2',4,4',5,6'-hexachlorobiphenyl; 2,2',3,4,5,6,6'-heptachlorobiphenyl was used rather than 2,2',3,4',5,6,6'-heptachlorobiphenyl; and 2,2',3,3',5,5',6,6'-octachlorobiphenyl was used rather than 2,2',3,3',4,5',6,6'-octachlorobiphenyl. A different congener standard was used to establish retention time windows for scanning with selected ions.

Only single-point calibrations were used for GC/MS and GC/ECD standards (although five-point calibrations were specified to the laboratory); hence, the results must be considered estimates only.

Laboratory Analysis for Chlorinated Pesticides

The method originally specified is described in Tetra Tech (1986a). This procedure calls for extraction of a 100-g wet weight sample with removal of 20 percent of the extract for GC/ECD analysis of pesticides and PCBs. For this project, the pesticide/PCB fraction was extracted separately from the A/B/N extract to be analyzed by GC/MS. A sample of 40 g (wet weight) was extracted and processed according to protocol.

The original statement of work submitted to CAL was verbally modified at the request of CAL after they received the samples. Instrumentation was modified from capillary column analysis to packed column analysis for both quantitation and confirmation according to EPA Contract Laboratory Program (CLP) procedures. A mixed phase 1.50 percent SP-2250 and 1.95 percent SP-2401 was used for the quantitation column. The confirmation column used was 3 percent SP-2100.

Most of the sample extracts were diluted to minimize interference from non-target compounds. Dilution factors were 10, 100, or 200. Detection limit specifications (0.1-5.0 ug/kg) were satisfied for samples not requiring dilution but were exceeded for diluted samples.

Laboratory Analysis for Resin Acids and Chlorinated Phenols/Guaiacols

Standard procedures for analysis of resin acids and chlorinated phenols/guaiacols in sediments are not available. Thus, dedicated analyses for these compound classes were developed in conjunction with Laucks Testing Laboratories (Seattle, Washington) and were validated with initial performance tests.

Extraction--

Wet sediment samples (roughly 40-50 g wet weight) were added to a precleaned Soxhlet thimble. Recovery surrogates were spiked into the sample prior to extraction: O-methylpodocarpic acid (a resin acid surrogate) [National Council of the Paper Industry for Air and Stream Improvement (NCASI) 1986] was added at 50 ug/sample and two phenolic surrogates, 2,6-dibromophenol and 2-bromo-4-chlorophenol, were added at 5 ug/sample. The sediment was rinsed with a solution of 0.5 mL acetic acid/50 mL methanol to remove as much water as possible and to reduce the extraction pH and thus enhance recoveries of the organic acid analytes. The acetic acid/methanol rinsate was stored for later use. The rinsed sediment was then Soxhlet extracted for 24 h with a mixture of 3:2 (v/v) acetone/hexane (azeotropic boiling point = 50° C).

Sample extracts were combined with the methanol rinsates and 200 mL of pre-cleaned water (pH <2) in a separatory funnel and were subjected to liquid-liquid extraction. After removal of the hexane layer, pentane and ethyl ether were used for additional extractions of the aqueous phase. Separatory funnel extracts were combined, dried with Na_2SO_4, and concentrated to a volume of 10 mL with a Kuderna-Danish (K-D) apparatus. The extracts were then split into two 5-mL aliquots for separate resin acid and chlorinated phenols analyses.

Derivatization--

Resin acids were methylated and chlorinated phenolics were acetylated before GC/MS analysis.

Resin Acids--Extract aliquots to be analyzed for resin acids were exchanged into ethyl ether, treated with 4 drops of methanol, and derivatized with diazomethane (CH_2N_2) to generate methyl esters. Derivatized extracts were exchanged to 1 mL of hexane for GC/MS analysis. Validation tests with a spiked extract demonstrated that 4 min of methylation were required for efficient methylation. When recovery of the surrogate compound (O-methylpodocarpic acid) suggested the possibility of inefficient derivatization, extracts were rederivatized. Samples were re-extracted when rederivatization had no apparent effect.

Chlorinated Phenols--Extract aliquots to be analyzed for chlorinated phenols were derivatized to generate acetate derivatives, which were far more amenable to GC analysis than the underivatized compounds. The 5-mL extracts were reduced in volume (0.5 mL) and treated with sodium acetate (1 g) and acetic anhydride (3 mL) in a 15-mL culture tube. After 1 h of heating at 60^o C, the derivatized extracts were cooled and water (3 mL) and hexane (3 mL) were added. The hexane layer was removed and the water was re-extracted twice with 3 mL of hexane. The hexane extracts were combined, dried with Na_2SO_4, and concentrated to 1 mL for GC/MS analysis.

The efficiency of derivatization was monitored on a sample-by-sample basis by including routine searches for the underivatized surrogate recovery compounds during GC/MS analysis. Underivatized surrogates were detected in three samples, but the areas of the underivatized compounds were always less than 5 percent of the areas of the derivatized compounds. Thus, rederivatization was considered unnecessary for these samples.

Instrumental Analysis--

Resin acids were analyzed by full-scan GC/MS and chlorinated phenolics were analyzed by GC/MS-SIM (selected ion monitoring).

Resin Acids by Full Scan GC/MS--Full scan analyses were performed with a fused silica capillary column (0.25 mm ID x 30 m, DB-5, J & W Scientific). The GC oven temperature was programmed from 35° C (held 5 min) to 300° C at 8° C/min (held at 300° C for 8 min). The injection internal standards were d_{10}-phenanthrene and d_{12}-chrysene. Qualitative identification was based on retention times and evaluation of mass spectra. All mass spectra were reviewed during QA evaluation.

Chlorinated Phenols by GC/MS-SIM--Chlorinated phenols were analyzed by GC/MS-SIM. This technique was chosen because full scan GC/MS analyses were considered insufficiently sensitive for analysis of chlorinated phenols. Seven ion descriptor windows were used in the 26-min analysis, with two to six ions per window. Two ions were scanned for each target compound. The two ions selected for each compound were typically the two most intense ions in their mass spectra; for a given compound, both ions represented the same molecular fragment, but differed by two atomic mass units (AMUs) because of the natural isotopic abundances of ^{35}Cl and ^{37}Cl. Such chlorine isotope peaks are characteristic features of spectra of chlorinated organic compounds. The spectra of the acetate derivatives were very similar to those of the underivatized compounds, because the parent ions including the acetate group were not predominant.

Because GC/MS-SIM analysis does not yield mass spectra, qualitative identification was based on comparison of retention times and chlorine isotope peak ratios to those of authentic standards. A compound was reported as undetected if its ion ratio in a sample differed by more than a factor of 2 from that in the standard. This criterion, while somewhat arbitrary, was based on the most extreme variations observed for the injection internal standards (d_8-naphthalene, d_{10}-acenaphthene, and d_{10}-phenanthrene). In most cases, ratios in samples agreed very well with those in standards and were well within a factor of 2. Co-eluting interferences were assumed to be a predominant source of variation of ion ratios in sample extracts. Of all analytes, 2,3,4,6-tetrachlorophenol most often had ion ratios that deviated from standards by more than a factor of 2.

Detection Limits--

Sample-specific detection limits for chlorinated phenols were based on instrumental sensitivity (i.e., 0.1 ng on-column, the lowest concentration standard used for initial calibration), final extract volume (1 mL), and sample weight. Several sample chromatograms were examined and the baseline noise was estimated in the retention time region of the target compounds. Detection limits were above three times the signal:noise ratio. Compounds reported between 0.05 and 0.1 ng on-column were qualified with an E, and compounds reported by the laboratory at <0.05 ng on-column were reported as undetected at the detection limit.

For resin acids, sample-specific detection limits were based on a 5 ng on-column instrumental sensitivity, final extract volume (1 mL), and sample weight. Although the lowest standard concentration used during initial calibration was 25 ng on-column, the laboratory analyzed a 5 ng on-column standard and demonstrated linearity from 5 to 150 ng on-column and acceptable mass spectra at 5 ng on-column. Hence, 5 ng on-column was considered a reasonable basis for detection limits. In fact, acceptable mass spectra were observed in many samples for compounds detected at <5 ng on-column. Compounds detected below the stated detection limits were reported with an E (estimated value) unless area counts were lower than 1000 units, in which case the compounds were reported as undetected. For all compounds except abietic acid, an area of 1000 units corresponded to 0.3 to 1.6 ng on-column; for abietic acid, the corresponding concentration was 4 ng on-column.

Initial Performance Tests--

Initial performance tests were conducted for resin acid and chlorinated phenols analysis because the overall procedures were not standardized or routine for the laboratory prior to this study. Results from spiked blank analyses for resin acids and chlorinated phenols (Table 9) were considered acceptable. The resin acid spiked blank analyses included a silica gel column chromatography cleanup step that was not used during sample analysis.

TABLE 9. RESULTS OF INITIAL PERFORMANCE TESTS
(SPIKED BLANKS)

	Spike Level (ug)	Percent Recovery		RPD[a]
		Run 1	Run 2	
Resin acids:				
Sandaracopimaric acid	1	65	61	6.3
Isopimaric acid	1	63	58	8.3
Palustric acid	1	47	39	19
Dehydroabietic acid	1	70	65	7.4
Abietic acid	2	49	47	4.2
Neoabietic acid	2	45	41	9.3
14-Chlorodehydroabietic acid	1	54	56	3.6
12-Chlorodehydroabietic acid	1	56	56	0
Dichlorodehydroabietic acid	1	63	65	3.1
Chlorinated Phenols[b]:				
2-Chlorophenol	0.04	89	76	16
2,4-Dichlorophenol	0.04	96	87	9.8
2,4,6-Trichlorophenol	0.04	82	76	7.6
2,4,5-Trichlorophenol	0.04	86	78	9.8
2,3,4,6-Tetrachlorophenol	0.04	97	76	24
Pentachlorophenol	0.04	87	75	15
4,5,6-Trichloroguaiacol	0.04	92	61	41
Tetrachloroguaiacol	0.04	84	67	23
2,6-Dibromophenol[c]	0.10	96	94	2.1
4-Bromo-2-chlorophenol[c]	0.10	85	84	1.2

[a] Relative percent difference.

[b] 3,4,5-Trichloroguaiacol was not added.

[c] Surrogate compound.

Laboratory Analysis for Volatile Organic Compounds

Sample analysis followed a hierarchical procedure based on results for selected samples. Thirty-five samples were delivered to Analytical Resources, Inc. (Seattle, Washington). Ten samples were designated to be analyzed only if target compounds were detected in specified associated samples. None of the 10 contingency samples required analysis.

Samples were analyzed by EPA/CLP procedures for volatile organic compounds (purge-and-trap GC/MS).

Ancillary Analyses

Grain Size--

Grain-size determinations were performed by Battelle Northwest Marine Research Laboratory (Sequim, Washington). Approximately 25 g of homogenized wet sediment was treated with hydrogen peroxide to remove organic material. Sediment was then wet-sieved through a 0.0625-mm screen and the fines were collected in a cylinder. Sand and gravel fractions (0.0625 to >2 mm) were wet-sieved and then dried to constant weight at 90° C. The silt-clay fraction (<0.004 to 0.0625 mm) was treated with a preweighed dispersant and analyzed by pipetting 20 mL at 30-sec intervals for 10-in depth, and 59-min intervals for 5-cm depth. Pipetted samples were dried at 90° C to constant weight and then corrected for dispersant weight. Results were calculated based on total weight of the eight fractions. The following size fractions were evaluated:

gravel - >2 mm
very coarse sand - 1-2 mm
coarse sand - 0.5-1 mm
medium sand - 0.25-0.5 mm
fine sand - 0.125-0.25 mm
very fine sand - 0.0625-0.125 mm
silt - 0.004-0.0625 mm
clay - <0.004 mm.

Sulfides--

Water-soluble sulfides were measured by AmTest, Inc. (Redmond, Washington) according to the method described in Green and Schnitker (1974). In this method, a 0.005 or 0.05 M Pb $(ClO_4)_2$ titrant was used for sample titration.

Total Organic Carbon and Total Nitrogen--

Total organic carbon and nitrogen were analyzed by Weyerhaeuser Analytical and Testing Services (Federal Way, Washington), using a Carlo-Erba NA 1500 Elemental Analyzer and following PSEP protocols.

Quality Assurance/Quality Control Results

Reviews of sediment chemistry data were performed in accordance with PSEP guidelines (Tetra Tech 1986g). QA/QC reviews of chemistry included assessments of accuracy [using standard reference materials (SRM), matrix spikes, and surrogate recoveries, when applicable], precision (using analytical replicates), initial and ongoing calibration and tuning, blank results, sample holding times, and initial performance tests or validation data for certain non-CLP procedures.

Detailed QA reports were prepared for chemical analyses and were compiled in a single document (Tetra Tech 1988a). These reports are not reproduced here, but are summarized below.

Metals--

The sample results are considered acceptable as qualified. Because precision control limits were exceeded for antimony, all positive antimony data are considered to be estimated and were assigned an "E" qualifier.

Assessment of the Effect of Analytical Procedure on Metals Results--The analytical methods used to determine metals in this study were designed to measure the total concentrations of metals in sediments (including mineral-bound components), in contrast to methods that rely on partial digestion. A small study was conducted (PTI and Tetra Tech 1988) to examine the implications of using the "total metals" methods, especially when comparing results to historical reference area data generated by "strong acid" methods (e.g., reference area data from Carr Inlet). The analytical methods used in the present study were the same as those used by PTI and Tetra Tech (1988) and analyses were performed by the same laboratory (Battelle Northwest Marine Research Laboratory).

Two archived Carr Inlet samples collected during the Commencement Bay Remedial Investigation (Tetra Tech 1985a) were analyzed in triplicate by "total metals" methods used in the present study and by the "strong acid" method (per EPA CLP) used during the Commencement Bay study. In addition, selected samples collected during the Elliott Bay study (PTI and Tetra Tech 1988) were reanalyzed by the "strong acid" method for comparison purposes. The results are presented in Table 10.

Although differences were observed for a number of metals analyzed by both methods, the consistently largest differences were observed for chromium (Table 10). In both Carr Inlet samples, mean chromium concentrations by "total metals" methods (in this case, XRF) were over 4 times the mean concentrations determined by the "strong acid" technique. Samples with higher overall chromium concentrations from Port Susan and Elliott Bay/Duwamish River (PTI and Tetra Tech 1988) tended to have approximately a factor of 2 difference between "total metals" and "strong acid" results.

Differences between antimony results by "total metals" vs. "strong acid" methods could not be determined for Carr Inlet samples because antimony was consistently undetected by the "strong acid" procedure (Table 10). However, data reported for Samples CR-11 and CR-13 during the Commencement Bay Remedial Investigation were roughly 15 times lower than the "total metals" values in Table 10. Similarly, for Duwamish River Samples WW-12 and EW-15, the "total metals" procedure (including hydrofluoric acid digestion and analysis by GFAA) resulted in antimony concentrations roughly 10-20 times higher than concentrations determined by the "strong acid" procedure. This

TABLE 10. COMPARISON OF ANALYTICAL METHODS FOR SELECTED METALS

	Sample	Technique	Antimony	Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Silver	Zinc
Reference Area Samples	CR-11 (n=3)	Total metal[a]	1.91 ± 0.16[b]	4.47 ± 0.79	0.09 ± 0.01	99 ± 26	9.8 ± 1.6	4.4 ± 1.2	17.7 ± 3.1	0.043 ± 0	28.2 ± 1.7
	CR-11 (n=3)	Strong acid[c]	U0.92 ± 0	2.07 ± 0.09	0.13 ± 0.01	19 ± 1.5	6.1 ± 0	3.6 ± 0.1	13.8 ± 1.3	0.027 ± 0.002	19.3 ± 0.58
	CR-13 (n=3)	Total metal	1.40 ± 0.18	3.69 ± 1.1	0.19 ± 0.02	84 ± 10	12.6 ± 0.36	8.1 ± 0.55	20.6 ± 0.85	0.076 ± 0.029	34 ± 2
	CR-13 (n=3)	Strong acid	U0.92 ± 0	2.48 ± 0.52	0.22 ± 0.01	19 ± 1.5	6.73 ± 1.4	2.2 ± 0.60	15.1 ± 1.3	0.022 ± 0.007	19 ± 0.6
	PS-01 (n=1)	Total metal	2.66			236	49.8	10.4	139		
	PS-01 (n=3)	Strong acid	U0.92 ± 0			133 ± 2	43.3 ± 1.1	5.6 ± 2.4	130 ± 2		
Elliott Bay/ Duwamish River Samples	WW-12 (n=1)	Total metal	1,200			555	618	1,180	100		
	WW-12 (n=2)	Strong acid	59 ± 6.6			266 ± 12	920 ± 33	1,510 ± 69	87 ± 3.6		
	WW-12 (n=1)	XRF[d]	240								
	EW-15 (n=1)	Total metal	150			223	176	210	63.8		
	EW-15 (n=2)	Strong acid	14 ± 1.2			115 ± 2.8	305 ± 33	330 ± 40	45.9 ± 2.7		
	EW-15 (n=1)	XRF	32								
	NH-04 (n=1)	Total metal	504								
	NH-04 (n=1)	XRF	120								
	KG-06 (n=1)	Total metal	192								
	KG-06 (n=1)	XRF	27								
	WW-14 (n=1)	Total metal	1,370								
	WW-14 (n=1)	XRF	217								
	SS-09 (n=1)	Total metal	680								
	SS-09 (n=1)	XRF	547								

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[a] Methods used in the present study: digestion with nitric, perchloric, and hydrofluoric acids and analysis by AA (for antimony, cadmium, and silver) or x-ray fluorescence (for arsenic, chromium, copper, lead, nickel, and zinc).

[b] Mean ± standard deviation. All concentrations are in mg/kg DW.

[c] EPA CLP procedure involving digestion with nitric acid and hydrogen peroxide.

[d] X-ray fluorescence.

marked discrepancy prompted reanalysis by an independent and more reliable technique for antimony (i.e., XRF). Comparisons between XRF and the "total metals" procedure used in this study were confounding (Table 10), but suggest that antimony concentrations observed during this study could be considerable overestimates (e.g., by a factor of approximately 5).

The XRF analysis of antimony aroused sufficient uncertainty about the antimony concentrations reported in this study that antimony data were not used to define or rank problem areas. However, antimony distributions are discussed in the **Results** section because of their potential value in assessing relative antimony contamination in Everett Harbor.

Semivolatile Organic Compounds--

The data for A/B/N organic compounds are generally acceptable. The laboratory followed specified protocols with the following exceptions:

- The relative response factor for N-nitrosodiphenylamine was outside control limits (25 percent difference) for 11 of the 15 daily standard analyses. Positive sample results for N-nitrosodiphenylamine in all samples associated with the 11 standard analyses have been qualified in the database with an "E" (estimated).

- Benzoic acid levels in one of four blanks exceeded the PSEP control limit of 2.5 ug total (Tetra Tech 1986g). Analyses were not halted while investigating the cause of contamination. Therefore, benzoic acid values for the batch of samples run with this blank were qualified with an "E" after blank correction.

Method blanks were analyzed with each extraction batch. Phenanthrene, pyrene, phenol, naphthalene, and 2-methylnaphthalene were detected at relatively low levels in some blanks (Table 11).

TABLE 11. METHOD BLANK SUMMARY

Lab ID	Date Extracted	Date Analyzed	Compound	Concentration[a] (ug/kg DW)	CRDL[b]
26987018	12/1/86	1/1/87	Phenanthrene	4	10
			Di-n-butyl phthalate	26	10
			Pyrene	3	10
			Bis(2-ethylhexyl)phthalate	46	10
27987036	12/8/86	1/14/87	Phenol	32	25
			Naphthalene	2	10
			Benzoic acid	160	10
			Di-n-butyl phthalate	160	10
			Bis(2-ethylhexyl)phthalate	48	10
			Di-n-octyl phthalate	4	10
26987054	12/10/86	1/19/87	Phenol	20	25
			Naphthalene	4	10
			Di-n-butyl phthalate	15	10
			Pyrene	2	10
			Bis(2-ethylhexyl)phthalate	44	10
			Di-n-octyl phthalate	28	10
			2-Methylnaphthalene	2	10

[a] Concentrations in blanks are based upon 80 g wet weight of sediment and an assumed 50 percent moisture. These values provide a means for comparison of blank contamination to observed concentrations in sediment samples.

[b] Contract required detection limit.

PCBs--

The PCB data are considered acceptable when qualified as estimates. Qualification was necessary because only a single-point calibration was used for quantification. All positive results above 50 ug/kg DW in the database were generated by GC/MS analyses because of interferences encountered during GC/ECD analyses. Precision (based on blind replicates), and accuracy (based on matrix spikes and SRM) for these analyses were well within PSEP limits except for the results of one matrix spike (EW-04MS), in which the PCB concentration was considerably lower than in the unspiked sample. This discrepancy was not explained. However, the relatively high concentration in unspiked sample EW-04 was confirmed by re-extraction and re-analysis. Extracts for GC/MS analysis were held longer than the 40-day holding time specified by the EPA CLP. The extended extract holding time may have resulted in an underestimate of original sample concentrations, although degradation of PCBs in solvent is not expected because of the well-documented stability of this class of compounds (e.g., Hutzinger et al. 1974).

Chlorinated Pesticides--

Many chlorinated pesticide samples required dilution because of interferences, resulting in higher detection limits than those specified in the "Quality Assurance Project Plan for Field Investigations to Support Development of the Everett Harbor Action Plan" (Tetra Tech 1986f). In addition, because of sample dilutions, no precision and accuracy data were obtained for this sample set. However, the review of calibration data suggests that the analytical instrument was operating within acceptable limits. PSEP protocols were used to assess the acceptability of data and data qualifiers were not assigned to pesticide results.

Resin Acids and Chlorinated Phenols/Guaiacols--

Overall, data for resin acids and chlorinated phenols/guaiacols are considered acceptable. Palustric acid data were rejected based on 0 percent recoveries in both matrix spikes; this was not an unexpected result, as this compound is susceptible to isomerization and degradation during analysis

(NCASI 1986). Data reported by the laboratory were changed to detection limits during QA review if they did not exceed blank values by a factor of 5 or, for chlorinated phenols, if ion ratios in samples differed from those in standards by a factor of 2 or more. Data were qualified with an "E" for several possible reasons: 1) if data were reported at a concentration corresponding to less than half the lowest calibration standard; 2) if data were associated with an ongoing calibration that was outside PSEP limits; or 3) if mass spectra were only marginally acceptable (applicable to only a few reported values).

In the two sets of duplicate analyses performed for resin acids, precision exceeded the 100 percent PSEP control limit for three resin acids in one set of duplicates (sandaracopimaric acid, isopimaric acid, and abietic acid) (Table 12). Data were not qualified based on precision because several lines of evidence suggested that the low precision for several compounds in Station EW-07 (Table 12) was the result of heterogeneous sample contamination and/or matrix effects rather than analytical error. This argument is based on the following lines of evidence:

- Duplicate spiked blank analyses (see Table 9) resulted in precision of 0 to 9 percent for all resin acids (except palustric acid, which was rejected)

- Precision for matrix spikes of two relatively uncontaminated samples was $\leq$11 percent for all resin acids (Table 13)

- Precision for resin acids at Station SS-03 (Table 12), which was a far less complex sediment matrix than Station EW-07 in terms of contaminant assemblage and sediment texture (e.g., organic carbon content), ranged from 7.4 to 50 percent for the three resin acids detected at Station SS-03 (the detected resin acids included two of the three resin acids with >100 percent precision at Station EW-07).

TABLE 12. PRECISION FOR RESIN ACIDS

Compound	EW-07[a] (ug/kg)	EW-16[a] (ug/kg)	$\bar{x}$	RPD[b]
Sandaracopimaric acid	E350	3,800	E2,100	170
Isopimaric acid	E760	6,200	E3,500	160
Palustric acid	U500	U300	--	--
Dehydroabietic acid	6,300	9,500	5,100	41
Abietic acid	3,200	14,000	8,600	130
Neoabietic acid	E240	680	E460	96
14-Chlorodehydroabietic acid	1,400	1,600	1,500	13
12-Chlorodehydroabietic acid	4,100	5,400	4,800	27
Dichlorodehydroabietic acid	E640	770	E710	18

Compound	SS-03 (ug/kg)	SS-03 Dup (ug/kg)	$\bar{x}$	RPD[b]
Sandaracopimaric acid	E34	E85	E60	86
Isopimaric acid	E130	E140	E140	7.4
Palustric acid	U170	U210	--	--
Dehydroabietic acid	E180	E300	E240	50
Abietic acid	U170	U210	--	--
Neoabietic acid	U170	U210	--	--
14-Chlorodehydroabietic acid	U170	U210	--	--
12-Chlorodehydroabietic acid	U170	U210	--	--
Dichlorodehydroabietic acid	U170	U210	--	--

[a] EW-07 and EW-16 were blind duplicates.

[b] Relative percent difference.

TABLE 13. RESULTS OF MATRIX SPIKES - RESIN ACIDS

Compound	Spike Level (ug)[a]	Percent Recovery		Average Percent Recovery	RPD[b]
		SS-03	PS-03		
Sandaracopimaric acid	50	88	92	90	4.4
Isopimaric acid	50	82	87	85	5.9
Palustric acid	50	0	0	0	0
Dehydroabietic acid	50	98	88	93	11
Abietic acid	100	83	87	85	4.7
Neoabietic acid	100	62	58	60	6.7
14-Chlorodehydroabietic acid	50	84	93	89	10
12-Chlorodehydroabietic acid	50	84	92	88	9.1
Dichlorodehydroabietic acid	50	79	85	82	7.3

[a] These spiking levels correspond to 1,300-1,800 ug/kg DW (twice these concentrations apply for abietic and neoabietic acid).

[b] Relative percent difference.

Volatile Organic Compounds--

The data for volatile organic compounds are acceptable with the exception of data for methylene chloride (a common laboratory contaminant). Methylene chloride values were rejected because of excessive blank contamination.

Ancillary Analyses--

The overall quality of sulfide data is acceptable. However, the 7-day holding time limit recommended by PSEP (Tetra Tech 1986g) was exceeded for 51 of 64 samples collected. The effect of holding time exceedance is not clear. Technical holding times have been established only for water matrices. It is possible that sample integrity was compromised by biological or chemical changes occurring in the sample. Sulfide concentrations can decrease due to the degassing of hydrogen sulfide or the oxidation of sulfides to elemental sulfur. The observation of undetected sulfide (detection limit = 20 mg/kg DW) reported for Station EW-01 was probably an analytical error, based on the extremely strong sulfur odor that was recorded in field notes during sample collection and processing.

Data for grain size, total organic carbon, and total nitrogen were acceptable without qualification.

BIOACCUMULATION

Field Sampling

English sole (Parophrys vetulus) were sampled at 10 transects in Everett Harbor and at 1 transect at Port Susan, a nonurban reference area (see Figure 6). Port Susan was used as a reference area because previous studies have found that the area is relatively uncontaminated (Malins et al. 1982). In addition, Malins et al. (1984) found no serious hepatic lesions in English sole collected from that embayment.

Sampling of English sole was conducted between 25 August and 2 September 1986. Fish were collected using a 7.6-m (headrope) Marinovich otter trawl having a body mesh size of 3.2 cm (stretched) and cod-end liner mesh size of 0.8 cm (stretched). Trawling was conducted along each transect at a constant vessel speed of approximately 2.5 kn during daylight hours (0800-1730 h).

Five of 60 English sole (>220 mm) that were collected for histopathological analysis (see below, **Fish Ecology and Histopathology**) were selected for analysis of PCBs, EPA priority pollutant pesticides, and mercury in raw muscle tissue. After removal of liver and otoliths, each fish was wrapped in aluminum foil and stored on ice until transfer to the freezer at -20° C. In the laboratory, fillets of dorsal muscle tissue were excised and skinned with a stainless steel spatula in preparation for analysis.

Dungeness crabs (Cancer magister) were collected between 25 August and 21 October 1986 primarily from otter trawls conducted for fish sampling and from crab pots deployed near the trawl stations. Crabs from the East Waterway (Station EW-91) were obtained from a crab pot fisherman at Pier 1. Male crabs were selected from the catch at each site, placed in polyethylene bags, and stored live on ice. At the end of each sampling day, samples were transferred to a freezer and stored at -20° C until analysis. In the laboratory, crabs were thawed, and samples of cheliped tissue from eight crabs were composited into a single sample per site. Two additional replicate composite samples were analyzed for Station EW-91.

Laboratory Analysis for Mercury

Mercury was the only EPA priority pollutant metal analyzed in fish and crab tissue because of its high potential for bioaccumulation. Digestion and instrumental techniques followed PSEP protocols (Tetra Tech 1986g). Muscle tissue was homogenized and subjected to nitric acid/perchloric acid digestion at Battelle Northwest Laboratories (Sequim, Washington). The digestate was analyzed by cold vapor atomic absorption spectrophotometry.

Laboratory Analysis for PCBs/Pesticides

Extraction and Cleanup--

The analytical procedure used by Battelle Northwest Laboratories (Sequim, Washington) was derived from Tetra Tech (1986b). Only the sections relevant to analysis of PCBs and pesticides were followed. The procedure involves Soxhlet extraction with CH_2Cl_2/MeOH (2:1, vol/vol), extract cleanup by gel permeation chromatography (Biobeads S-X3; elution with CH_2Cl_2) and alumina column chromatography, and capillary column GC/ECD. Several notable exceptions to the Tetra Tech (1986b) procedure were cited in the laboratory's cover letter:

- Soxhlet extraction was carried out for 12 h rather than the specified 24 h

- Rotary evaporation was used for extract concentration rather than the specified K-D apparatus.

These two modifications did not appear to affect laboratory performance based on results of initial laboratory performance tests with SRMs and spiked blanks conducted by Battelle during a previous study (PTI and Tetra Tech 1988).

GC/ECD Analysis and Quantification--

Pesticides and PCBs were analyzed by capillary column GC/ECD with a DB-5 quantification column (0.25-mm i.d. x 30 m, J & W Scientific) and a SP-608 (Supelco, Inc.) confirmation column. The 80-min temperature program used for these samples allowed for a high degree of chromatographic resolution [roughly 76 peaks were resolved in a PCB standard consisting of Aroclor 1242:1254:1260 (1:1:1, wt/wt/wt)].

The quantification procedure used for PCBs is described in Tetra Tech (1986b). The procedure involves peak-by-peak quantification using an internal standard. Relative response factors for resolved peaks in a PCB standard containing Aroclors 1242, 1254, and 1260 (the range of PCB congeners expected in environmental samples) were determined by measuring the individual peak concentrations by GC/MS and then using dilutions of the same standard for initial and ongoing GC/ECD calibrations.

Extracts containing pesticides identified on the DB-5 column were rerun on the SP-608 confirmation column.

Quality Assurance/Quality Control Results

Reviews of bioaccumulation data were performed in accordance with PSEP guidelines (Tetra Tech 1986g). QA/QC reviews included assessments of accuracy (using standard reference materials, matrix spikes, and surrogate recoveries, when applicable), precision (using analytical replicates), initial and ongoing calibration and tuning, blank results, and sample holding times.

Detailed QA reports were prepared for chemical analyses and were compiled in a single document (Tetra Tech 1988a). These reports will not be reproduced here, but are summarized in this section.

Mercury Bioaccumulation--

Mercury data exhibited accuracy and precision within the guidelines established by PSEP (Tetra Tech 1986g). However, because the 28-day maximum sample holding time recommended by PSEP was exceeded for all of the tissue samples analyzed, sample results for mercury are considered to be estimates and were assigned an "E" qualifier.

PCB/Pesticide Bioaccumulation--

All detected data for PCBs in tissue were qualified as underestimates ("G", or greater than) because of low analytical recoveries observed throughout the sample case. Recoveries of the two surrogate compounds [4,4'-dibromooctafluorobiphenyl (DBOFB) and isodrin] in most samples, and PCB recoveries in all three tissue matrix spikes, were below PSEP limits of 50 percent for accuracy (Tetra Tech 1986g). An interlaboratory comparison with selected tissue samples and using a similar extraction/cleanup procedure confirmed the low PCB recoveries for Battelle. The cause of the low recoveries could not be identified and recoveries did not improve during re-extraction and re-analysis of selected samples. In addition, an "E" qualifier was assigned to samples associated with ongoing calibrations that were outside control limits. Sample and extract holding times exceeded PSEP guidelines; however, the target analytes (particularly PCBs) are not very susceptible to microbial or chemical alteration, particularly at the reduced temperatures of storage. No additional qualification was considered necessary to address holding time exceedances.

SEDIMENT BIOASSAY

Field Sampling

Sediment toxicity tests with Rhepoxynius abronius were performed at 29 stations in the Everett Harbor system and three stations in the reference area (Port Susan). A subsample of the composite sediment sample collected for chemical analyses was tested for toxicity using the amphipod bioassay. Field collection methods for sediment samples are described above (see **Sediment Chemistry, Field Sampling**).

The infaunal amphipod R. abronius was collected subtidally from West Beach on Whidbey Island (Washington) using a bottom dredge. Amphipods were maintained and transported in clean coolers with ice, and were returned to the laboratory within 18 h of collection.

Laboratory Analysis

Following their arrival in the laboratory, amphipods were kept in holding containers filled with fresh seawater (28 ppt salinity) and clean sediment and maintained at $15\pm1^{\circ}$ C under continuous light until used in testing. Cultures were aerated but not fed during acclimation and were held for not more than 10 days. Prior to testing, amphipods were sorted by hand from sediments and identifications were confirmed using a Wild M5 dissecting microscope. Damaged, dead, or unhealthy individuals were discarded.

Interstitial salinities of all test sediments were measured before testing. Of the 34 sediments tested (32 stations plus two field replicates), 10 had interstitial salinities less than 25 ppt: samples from Stations ES-01, ES-02, ES-03, NG-12, NG-14, SR-01, SR-02, SS-01, SS-03, and SS-07. In each case, interstitial salinity was elevated to at least 25 ppt by mixing the sediment with water of a sufficiently high salinity following methods outlined by PSEP protocols (Tetra Tech and E.V.S. Consultants 1986).

Acute lethality of amphipods exposed for 10 days to whole, fresh (unfrozen) sediments was measured using the methodology of Swartz et al. (1982, 1985) as amended by PSEP protocols (Tetra Tech and E.V.S. Consultants 1986). A 2-cm layer of test sediment was placed in 1-L glass jars and covered with 800 mL of clean seawater (28 ppt salinity). Each beaker was seeded (randomly and blindly) with 20 amphipods and aerated. Six replicates (20 amphipods each) were run per test sediment. Five beakers served to determine toxicity, while the sixth beaker served as a reference for daily measurement of water chemistry (i.e., pH, dissolved oxygen, salinity, and temperature). Testing was conducted at $15 \pm 1^{\circ}$ C under constant light. Test containers were checked daily to establish early trends in mortality and sediment avoidance, and also to gently sink any amphipods that had left the sediments overnight and become trapped by surface tension at the air/water interface. A negative (clean) control sediment from the amphipod collection site at West Beach, Whidbey Island was tested concurrently with each series of test sediments. Following PSEP protocols (Tetra Tech and E.V.S. Consultants 1986), cadmium-spiked ($CdCl_2$) seawater was used as a positive control to verify that the amphipods were responsive. Amphipod bioassays were initiated on all sediments within a 2-week period following field collection of sediments.

Bioassay tests were terminated after 10 days, when sediments were sieved (0.5-mm screen), and live and dead amphipods were removed and counted. Amphipods were considered dead when there was no response to physical stimulation and microscopic examination revealed no evidence of pleopod or other movement. Missing amphipods were assumed to have died and decomposed prior to the termination of the bioassay (Swartz et al. 1982, 1985).

Quality Assurance/Quality Control Results

Mean mortality ranged from 4 to 10 percent in the clean sediment (Whidbey Island) controls. A mean mortality of 10 percent is considered acceptable for amphipod sediment bioassay controls (Swartz et al. 1985). ANOVA indicated no significant differences ($P>0.05$) in mean mortality values among the clean sediment controls. Mortality in cadmium-spiked seawater was 100 percent, which is consistent with the expected mortality rate. Interstitial salinities in nine sediment samples were not acceptable according to PSEP Protocols (Tetra Tech and E.V.S. Consultants 1986) and were adjusted following the PSEP Protocols. Dissolved oxygen concentrations in water overlying the sediments in the bioassay chambers were acceptably high.

The amphipod bioassay results are considered acceptable for use in problem area identification. However, it should be noted that the data for the following stations showed high variance (standard error >12), generally due to an extreme outlier replicate: SR-07, EW-10, and OG-03.

BENTHIC MACROINVERTEBRATES

Field Sampling

Benthic macroinvertebrates were collected at 16 stations in the Everett Harbor study area and three stations in the Port Susan reference area between 30 September and 15 October 1986 (see Figure 5). Station depths ranged from 3.4 m to 21.4 m among the 19 stations. Most of the stations were located at depths of 7.9 m to 12.8 m, but it was not possible to sample within this depth range at all stations because of differences in shoreline bathymetry.

Five replicate grab samples were collected at each station, for a total of 95 samples. All samples were collected using a 0.1-m^2 modified van Veen grab sampler. In the field, samples were washed on a sieve with 1.0-mm mesh openings and fixed with a 10 percent solution of buffered formalin. Sample tracking records followed each sample through all stages of sample collection and laboratory processing.

The field sampling methods used to collect benthic macroinvertebrate samples during the Everett Harbor survey are outlined in the PSEP protocols (Tetra Tech 1986g) and the "Quality Assurance Project Plan for Field Investigations to Support Development of the Everett Harbor Action Plan" (Tetra Tech 1986f). The following discussion summarizes those procedures.

Following deployment and retrieval of the van Veen grab, it was placed in a sieve stand and the sediment sample was inspected carefully to determine the acceptability of the sample. Samples were rejected if excessive leakage or surface disturbance occurred. Samples were also rejected if they did not meet or exceed the following minimum penetration depths:

- Medium to coarse sand and gravel - 4 to 5 cm
- Fine sand and sandy silt - 7 to 10 cm
- Silt - 10 cm.

When a sample was judged to be acceptable, the following qualitative sediment characteristics were recorded:

- Penetration depth
- Sediment texture
- Sediment color
- Presence and strength of odors
- Degree of leakage and/or surface disturbance
- Presence of debris or shell fragments.

After the foregoing observations were recorded, the sampler was opened and the sediment was released into the top section of the sieving stand. The sediment was then washed from above with a gentle spray of seawater, and the larger masses of sediment were broken apart. Sediment was rinsed into a sieve box in the lower level of the sieving stand. The sediment in the sieve box was then completely washed until materials no longer passed through the 1.0-mm mesh screen. That portion retained on the screen was placed in a plastic sample bag having external and internal labels. Samples were then fixed in the field with a 10 percent solution of Borax-buffered formalin.

Laboratory Analysis

In the laboratory, benthic macroinvertebrate samples were washed on a 0.5-mm sieve and transferred to a 70 percent solution of isopropyl alcohol for long-term preservation. Organisms retained on the sieve were sorted into major taxonomic groups (e.g., polychaetes, molluscs, crustaceans, misc.) and enumerated. Planktonic organisms that occurred in the samples were not enumerated. Colonial organisms that occurred in the samples were noted as "present" but also were not enumerated.

Quality control checks of sample sorting were performed by resorting 20 percent of each sample. The 20-percent aliquot was taken after the entire sample had been spread out on a sieve with 0.025-mm mesh openings. If the 20-percent re-sort indicated a calculated difference of 5.0 percent or greater in total sample abundance for all taxa combined, the entire sample was resorted. Tetra Tech also performed independent quality control checks of sorting procedures (including checks of 20-percent aliquots) and checks of abundance counts for the major taxonomic groups. Samples that failed either quality control check were resorted completely.

Organisms in the samples from Everett Harbor and Port Susan (i.e., 19 stations) were identified to the lowest possible taxonomic level and enumerated. Specimens of each species (or lowest possible taxon) that occurred in the Everett Harbor study area were placed in reference museums prepared by the taxonomists.

Quality Assurance/Quality Control Results

QA/QC procedures resulted in an acceptable data set without qualification. Quality control checks of sample sorting, organism enumeration, and identification followed the guidelines recommended by PSEP protocols (Tetra Tech 1986g) and the "Quality Assurance Project Plan for Field Investigations to Support Development of the Everett Harbor Action Plan" (Tetra Tech 1986f).

FISH ECOLOGY AND HISTOPATHOLOGY

Field Sampling

Field sampling methods were described earlier (see **Bioaccumulation, Field Sampling**). English sole larger than 220-mm total length (TL) were selected for histopathological analysis. This size limit was used to ensure that most fish were greater than 2 yr old. A selection criterion based indirectly on age was used because English sole younger than 2 yr old have substantially lower prevalences of hepatic lesions than older fish (Malins et al. 1982). The present study therefore focused on those fish most likely to be afflicted with hepatic lesions.

Sixty English sole of appropriate length were collected at every transect, yielding a total of 714 fish for the overall study. Immediately after collection, each selected fish was sacrificed by a blow to the head, measured to the nearest millimeter (TL), examined for grossly visible external abnormalities (e.g., fin erosion, skin tumors, scoliosis, parasites), and transferred to the shipboard laboratory for liver removal.

In the shipboard laboratory, the liver of each fish was removed in its entirety, cut into multiple sections, and examined for the presence of grossly visible lesions. If lesions or discontinuities were noted, a subsample was taken from the affected area for histopathological analysis. If the liver appeared to be normal, a subsample was taken from the center of the organ at its broadest point. Each subsample was fixed in 10 percent neutral-buffered formalin. After the liver was removed from each individual, the sex of the fish was noted and the otoliths (sagittae) were removed for subsequent age determination.

All fishes in the remainder of the catch at each transect were identified to species and counted. All English sole not selected for histopathological analysis were measured (nearest mm TL) and counted.

Laboratory Analysis

Each formalin-fixed liver was dehydrated in a graded series of ethanol, cleared in xylene, and embedded in paraffin. Embedded livers were sectioned at 4 um using a rotary microtome and stained using hematoxylin and eosin (H&E). Prepared slides were examined using conventional light microscopy. Each slide was coded, so the pathologist did not know where the corresponding fish was captured. Lesion identifications were confirmed by Mr. M.S. Myers (Chief Pathologist, Northwest and Alaska Fisheries Center) to ensure their consistency with the identifications made by Malins et al. (1980, 1982, 1984).

Three major kinds of idiopathic hepatic lesion were evaluated: neoplasms, foci of cellular alteration, and megalocytic hepatosis. Briefly, neoplasms include both benign and malignant tumors. Foci of cellular alteration are discrete clusters of altered cells that have specific staining characteristics and are suspected of being preneoplastic. Megalocytic hepatosis is a specific degenerative condition characterized by a marked increase in both nuclear and cellular diameters in the absence of cellular inflammatory responses.

Prevalences of all three major lesions have been found to be elevated in English sole from urban embayments of Puget Sound (e.g., Malins et al. 1984; Becker et al. 1987). In addition, Myers et al. (1987) found consistent patterns of co-occurrence of these lesions in English sole from Eagle Harbor. Based on those patterns of co-occurrence and comparisons with similar lesions induced in rodents following laboratory exposure to chemicals, Myers et al. (1987) concluded that megalocytic hepatosis, foci of cellular alteration, and neoplasms may be related sequentially in the progression towards hepatic neoplasia in English sole. In that scenario, the following steps are thought to occur:

- Megalocytic hepatosis and associated degenerative lesions are induced as the initial, subchronic to chronic manifestations of the cytotoxic effects of hepatocarcinogens. These lesions form the proper stimulus for a proliferative response.

- In the above environment favoring proliferation, foci of cellular alteration develop. Because these lesions are selectively resistant to the cytotoxic effects of hepatocarcinogens, they have a growth advantage over normal hepatocytes.

- Autonomous, neoplastic hepatocytes arise from the nonautonomous foci of cellular alteration to form neoplasms. This final transformation is probably a complex, multistep process of mutation followed by selection.

Quality Assurance/Quality Control Results

Lesion identifications were confirmed by Mark Myers of the National Marine Fisheries Service. To ensure consistent identification of lesions between the three pathologists for this project, each examined slides from every station. For all three major kinds of lesions, the numbers of each lesion identified by the three pathologists were very similar, implying consistent diagnostic criteria. In addition, the relative prevalences of neoplasms and foci of cellular alteration among stations and among lesion types were similar to results from previous studies by the National Marine Fisheries Service (Malins et al. 1980). Although the relative prevalences of megalocytic hepatosis among stations were consistent with patterns identified by Malins et al. (1980), the absolute values found during this study were considerably lower than those found by Malins et al. (1980). The pathologists were aware of this apparent discrepancy shortly after the laboratory analyses began and therefore paid particular attention to identifying the presence of this abnormality. In addition, a review of selected slides by M. Myers confirmed the relatively low prevalence of megalocytic hepatosis. Therefore, it was concluded that the prevalences observed in this study were accurate. The final histopathology data were considered acceptable without qualification.

DATA MANAGEMENT

To facilitate data storage, QC, and analysis; recent and historical data from the Urban Bay Action Programs have been incorporated into a microcomputer database. The database software performs a wide variety of retrievals, reports, and analyses. It also allows data to be transferred directly to other software (e.g., SPSS/PC+ and Lotus 1-2-3) for statistical analyses and graphic displays. A library system is incorporated into the database to document data sources, changes to data, and other information to be linked to sample measurements.

Data Organization

Data are linked so that related kinds of information can be retrieved together for interdisciplinary analyses. For example, sediment chemistry, infauna abundances, and bioassay data can be retrieved into a single table, based on common samples or stations. During data retrievals, data can be summarized across laboratory replicates and field replicates as requested by the user.

The database design requires that only actual measurements be recorded. For example, if cadmium was measured at all stations but one during a survey, no value for cadmium need be stored for that single station. This reduces ambiguity and complexity of the database as well as storage requirements and retrieval speed. For biological effects data, a distinction is made between "not significant" (as compared to a reference area) and "not evaluated."

Each data value is associated with a single survey and station. The survey identifies the sampling program responsible for data collection. The station coordinates identify a unique geographic position sampled during that survey. Stations are described by an identifier, latitude and longitude, and basin and subbasin codes. Samples collected at each station are further identified by a unique sample ID, the date of collection, and field replicate number. Data of any type can be retrieved by:

- Date - all dates or a specified range
- Survey - any survey or only data from one or more specific surveys
- Station - any station or only data from one or more specific stations
- Basin and subbasin - any basin/subbasin or only data from one or more specific basin/subbasin.

These criteria allow any subset of the data to be retrieved or combined for analysis.

Data Analysis

Procedures for summarization of data are programmed into the database, providing consistent treatment and formatting of the data for analysis and interpretation. These procedures include, for example, the ability to rank observations by station or chemical; create new variables (such as sums of HPAH and LPAH); construct species lists by replicate, sample, or station; and compare data to AET or other sediment quality values. Statistical analyses were carried out using SPSS/PC+, and Lotus 1-2-3 was used for other analyses and data manipulations.

Data Entry and Quality Control

QC of data entry was based upon technical evaluation of the data, automated error-checking procedures in the database, and consistent and reliable automated procedures for retrieving and summarizing the data. All additions of data and modifications to data were documented, and the appropriate document reference code linked to the affected samples. The date was automatically inserted in all permanent output from the database. Technical review of the data was carried out before data entry and during analysis and interpretation. Automated error-checking procedures were used to screen data to preclude erroneous codes, duplicate data, and insufficiently or incorrectly identified data (e.g., measurements that are not assigned to a previously defined station). All access to the database was carried out through a series of menus and prompts, ensuring that all summaries and analyses were carried out in a consistent and replicable manner.

RESULTS

Results of field investigations in the Everett Harbor system and Port Susan are presented in the following sections on sediment chemistry, bioaccumulation, sediment bioassays, benthic macroinvertebrates, and fish ecology and histopathology. An evaluation of data collected during the present study and comparisons with recent data from previous studies is provided in each section.

SEDIMENT CHEMISTRY

The following section provides a summary of chemical results for over 50 subtidal and intertidal sediment samples collected from the Everett Harbor system and an additional three samples collected from the Port Susan reference area. Not all target chemicals were measured at all stations. At 54 stations, chemical data were collected for 11 EPA priority pollutant metals, 54 acid/base/neutral EPA priority pollutant organic compounds, PCBs, 19 chlorinated pesticides (mostly EPA priority pollutants), 10 additional Hazardous Substance List compounds, and 15 selected TIO compounds (see Table 1). At 31 stations, including some of the 54 stations discussed above, eight resin acids and nine chlorinated phenols and chlorinated guaiacols were analyzed by dedicated procedures (see Table 1). Nineteen samples were also analyzed for 35 volatile organic compounds (mostly EPA priority pollutants). TBT was measured at two stations. In addition, sediment conventional variables (e.g., grain size distribution and total organic carbon content) were analyzed in all 60 sediment samples. The objectives of this section are to:

- Provide a chemical perspective of the Everett Harbor study area, including the general distributions, concentration ranges, and frequencies of detection of chemical contaminants

- Determine the magnitude of contamination relative to reference area conditions and to determine the significance of this contamination relative to Puget Sound reference areas

- Summarize spatial correlations to define groups of chemicals with similar distribution patterns

- Interpret historical data to supplement the sediment chemistry results of the present study.

All chemical data and sediment conventional data are presented in Appendix B.

Normalization of Chemical Concentrations

Sediment concentrations presented in this report are typically expressed as the weight of contaminant per dry weight of sediment (e.g., ug/kg DW). Normalization of sediment concentrations to other variables [e.g., percent organic carbon or percent of fine-grained material (silt plus clay)] can aid in the interpretation of contaminant distributions by focusing on the most contaminated fractions of sediment, thus reducing the significance of variations in less important components of sediment texture and composition. The following is a brief description of each type of normalization.

Dry Weight Normalization--

Most sedimentary contaminants are associated primarily with the solid material in bulk sediments, not with the interstitial water. Thus, dry weight contaminant concentrations are preferred to wet-weight concentrations. Use of dry weight concentrations precludes the possibility that variations in sedimentary moisture content will obscure informative trends in chemical data.

Total Organic Carbon Normalization--

Chemical concentration gradients, particularly of nonpolar, nonionic compounds, have been observed to correlate well with sedimentary organic carbon content (e.g., Choi and Chen 1976). This observation is commonly interpreted in one of two ways:

1. Organic matter is the "active fraction" of sediment and serves as a sorptive sink for neutral, and possibly polar or metallic, compounds

2. Carbon-rich particles may be an important transport medium for contaminants [e.g., HPAH may be associated with soot particles (Prahl and Carpenter 1983)].

The occurrence of multiple contaminant sources in a localized area can obscure gradients of concentrations normalized to TOC content.

Strong correlations of dry weight chemical concentrations with TOC content, a good indication of the appropriateness of TOC normalization, were typically not observed in this study, even in the area with highly elevated TOC concentrations (the East Waterway). Thus, TOC normalization is mentioned infrequently in this section. Notably, many of the organic chemicals observed in this study were ionizable (e.g., phenols). Such relatively polar compounds do not conform well to the assumptions of organic carbon normalization theory.

Normalization to Percent Fine-Grained (<63 um) Particles--

On a limited spatial scale, contaminant concentrations are often inversely correlated with particle size (e.g., Lee 1985). Thus, contaminants (especially metals) may be concentrated in the fine-grained particles of bulk sediments. This observation is often explained in terms of surface area, in that finer particles have greater specific surface area, and thus greater sorption capacity, than larger particles. However, organic carbon content also tends to vary inversely with particle size in natural sediments (Choi and Chen 1976). Thus, normalizing to percent fines may be effectively equivalent to normalizing to organic carbon content in natural sediments.

Bulk Sediment Characteristics

Bulk sediment characteristics measured for this study included grain size distribution (as percent sand, silt, and clay), TOC, nitrogen, and water-soluble sulfides.

Grain Size--

Average percentages of fine-grained material in the seven study areas and Port Susan are presented in Figure 7. Several general trends are apparent. Sediments from Nearshore Port Gardner (Area NG) were the most coarse-grained of all study areas, probably because fine-grained material cannot accumulate under the existing current velocities and wave energies. Four of the NG stations were intertidal. Sediments further offshore in deeper water (Area OG) were more fine-grained. Sediments in Ebey Slough, Steamboat Slough, and the Snohomish River Delta study areas were relatively coarse. Most of the sediments collected from the Snohomish River were relatively coarse (<20 percent fines); however, Stations SR-04 and SR-05 had predominantly fine-grained sediments (>60 percent fine-grained material) and Station SR-07 (located in a sheltered area of the Snohomish River, outside the main channel) had the highest percentage of fine-grained material in the study (96 percent). Fine-grained sediments at these three SR stations are responsible for the elevated mean in Figure 7. Sediments in the East Waterway were typically the most fine-grained in the study, probably because of the proximity of sources of fine-grained material, and because of relatively quiescent conditions within the waterway. Sediment texture of Port Susan reference sediments collected during the 1986 Everett Harbor survey was relatively coarse (<15 percent fine-grained material at all three stations).

A more detailed summary of grain-size distributions in the East Waterway is presented in Figure 8. The stations are arranged geographically in Figure 8, with the eastern shore of the East Waterway at the bottom of the figure and the head (i.e., north end) of the waterway on the right side of the figure. Most sediments were predominantly fine-grained (>50 percent fine-grained material) with the finest sediment texture at the head of the

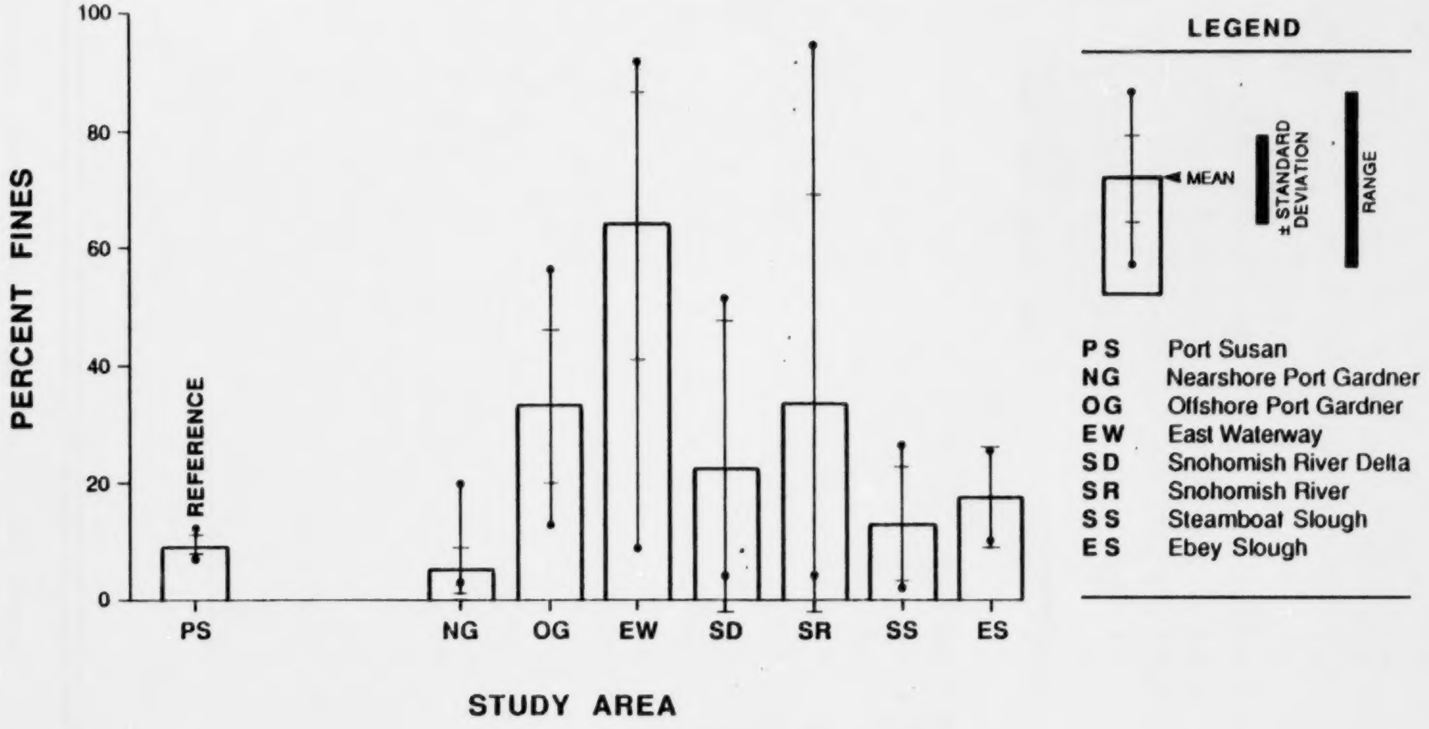


Figure 7. Average percent fine-grained material (silt plus clay) in sediments from all study areas.

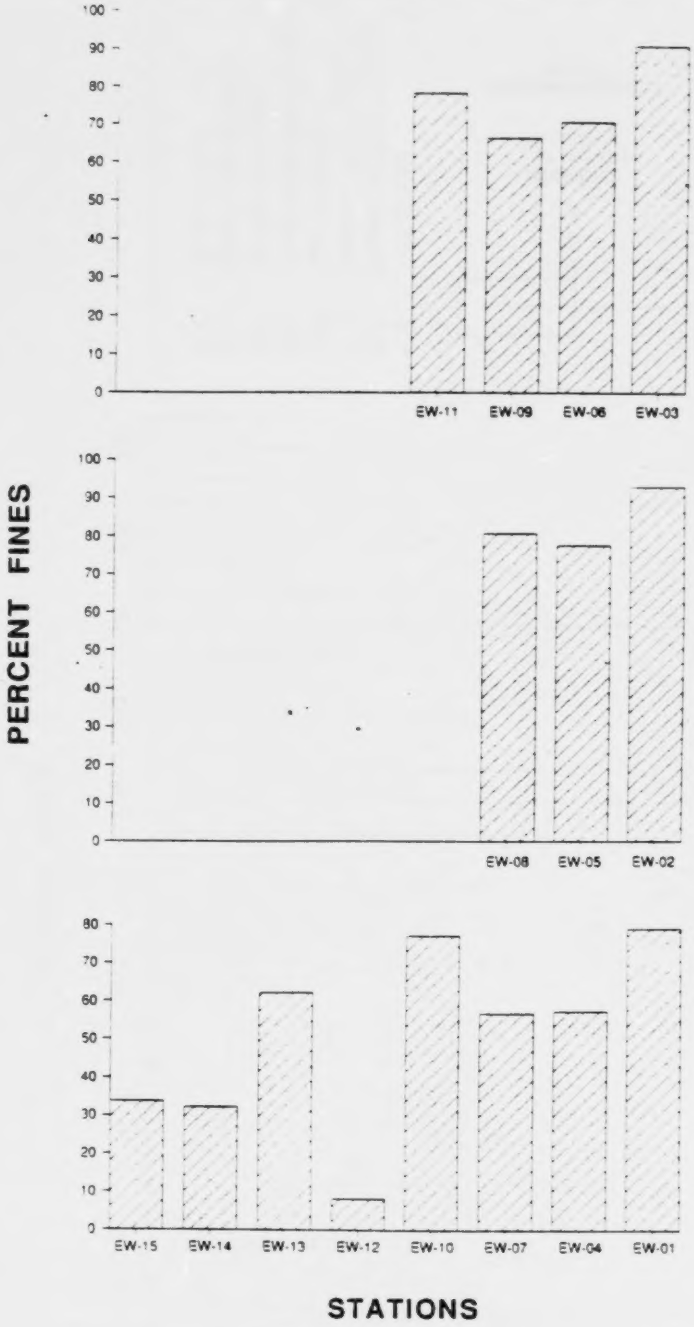


Figure 8. Percent fine-grained material (silt plus clay) in sediments of the East Waterway.

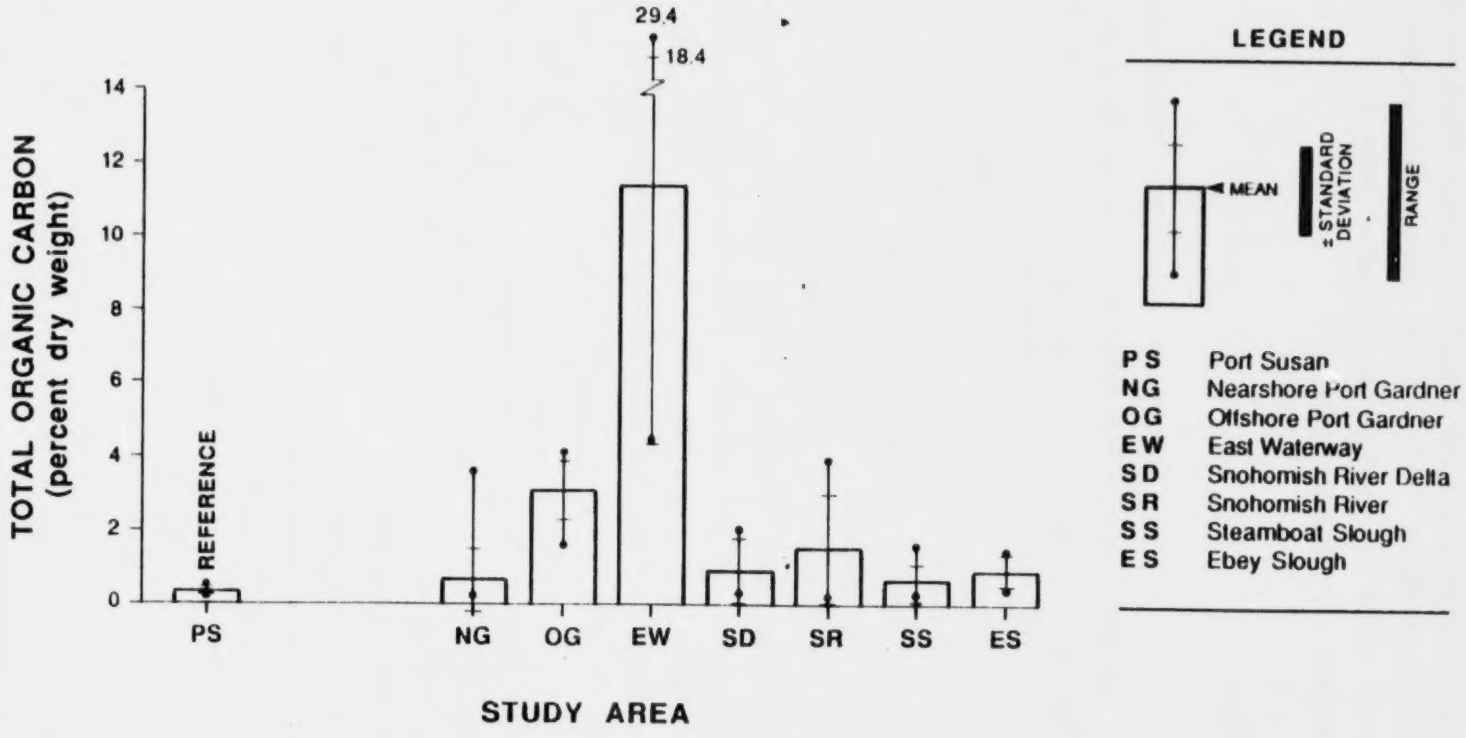


Figure 9. Average total organic carbon (TOC) content (as percent dry weight) in sediments from all study areas.

waterway (Stations EW-02 and EW-03, >90 percent fine-grained material). However, sediment at Station EW-12 was unusually coarse relative to other sediments along the east shore (<10 percent fine-grained material), and sediments at Stations EW-14 and EW-15 near the mouth were also relatively coarse (30 to 40 percent fine-grained material).

Total Organic Carbon--

Sediment TOC concentrations (Figure 9) displayed trends similar to those observed for percent fine-grained material. The correlation between percent fine-grained material and TOC was moderate ($r=0.71$, $n=60$, $P<0.05$), based on a regression that included all sediment stations. A comparison between sediments collected from nearshore and offshore Port Gardner illustrates this relationship. With the exception of a single station (NG-09), the relatively coarse-grained sediments collected in Area NG had less than 1 percent TOC content. The finer-grained offshore sediments (Area OG) had higher levels of TOC (2 to 4 percent). The relatively coarse sediments in Ebey Slough and Steamboat Slough displayed relatively low levels of TOC (<1 percent), as did sediments from the Snohomish River (with the exception of relatively fine-grained Stations SR-04, SR-05, and SR-07). The fine-grained sediments in the East Waterway had extremely high levels of TOC (mean of 11 percent, maximum of 29 percent).

A more detailed summary of TOC distributions in the East Waterway is presented in Figure 10. TOC and fine-grained content of sediments did not covary well within this waterway. Wastes rich in organic matter discharged into the East Waterway likely account for the highly elevated TOC levels in this area and for deviations from the inverse relationship between particle size and TOC content often observed in natural sediments. The highest levels of TOC were found at Stations EW-04 and EW-13 (23 to 29 percent), not in the very fine-grained sediments near the head of the waterway.

Average molar organic carbon to nitrogen (C/N) ratios in the seven study areas and Port Susan are summarized in Figure 11. The molar C/N ratio can provide information about the type of organic matter in the sediments. For example, marine phytoplankton are observed to have a C/N ratio of

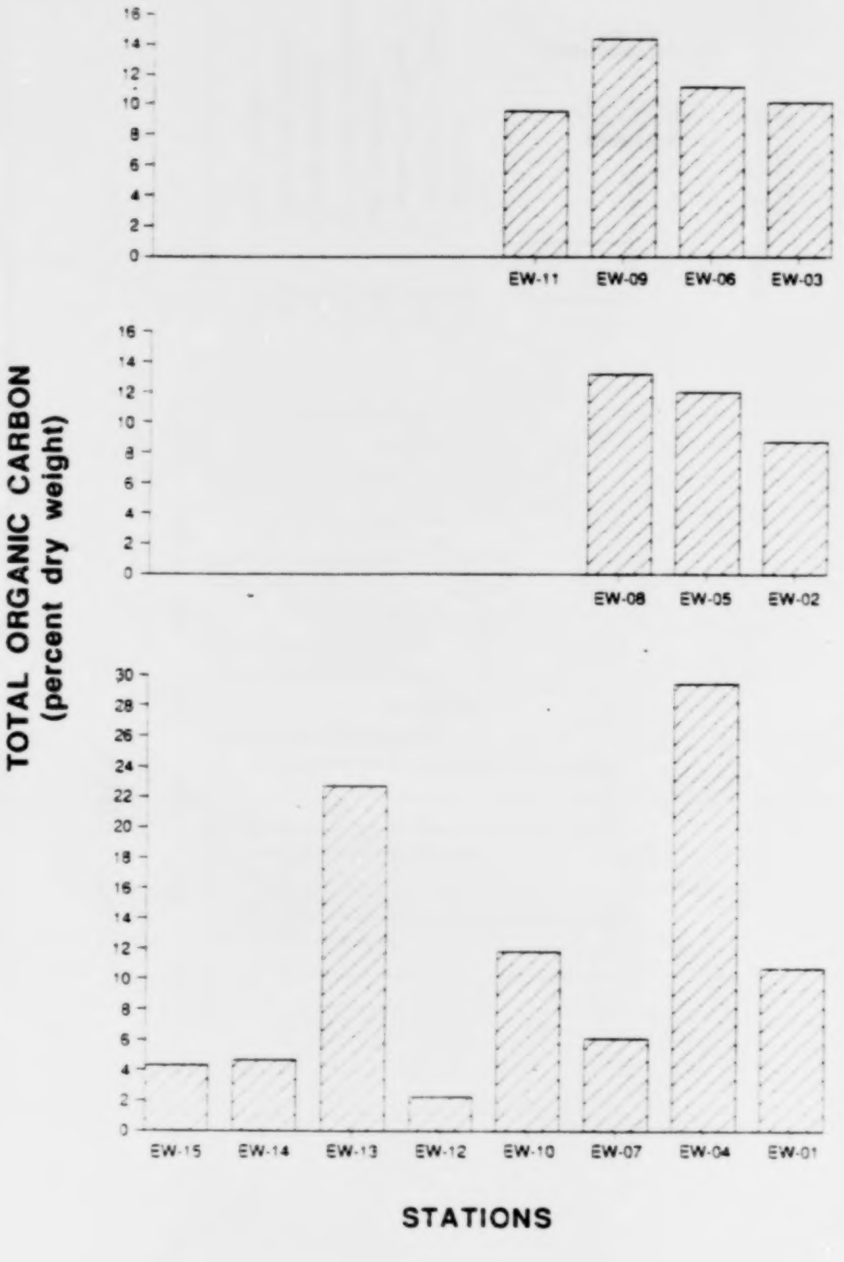


Figure 10. Total organic carbon (TOC) content (as percent dry weight) in sediments of the East Waterway.

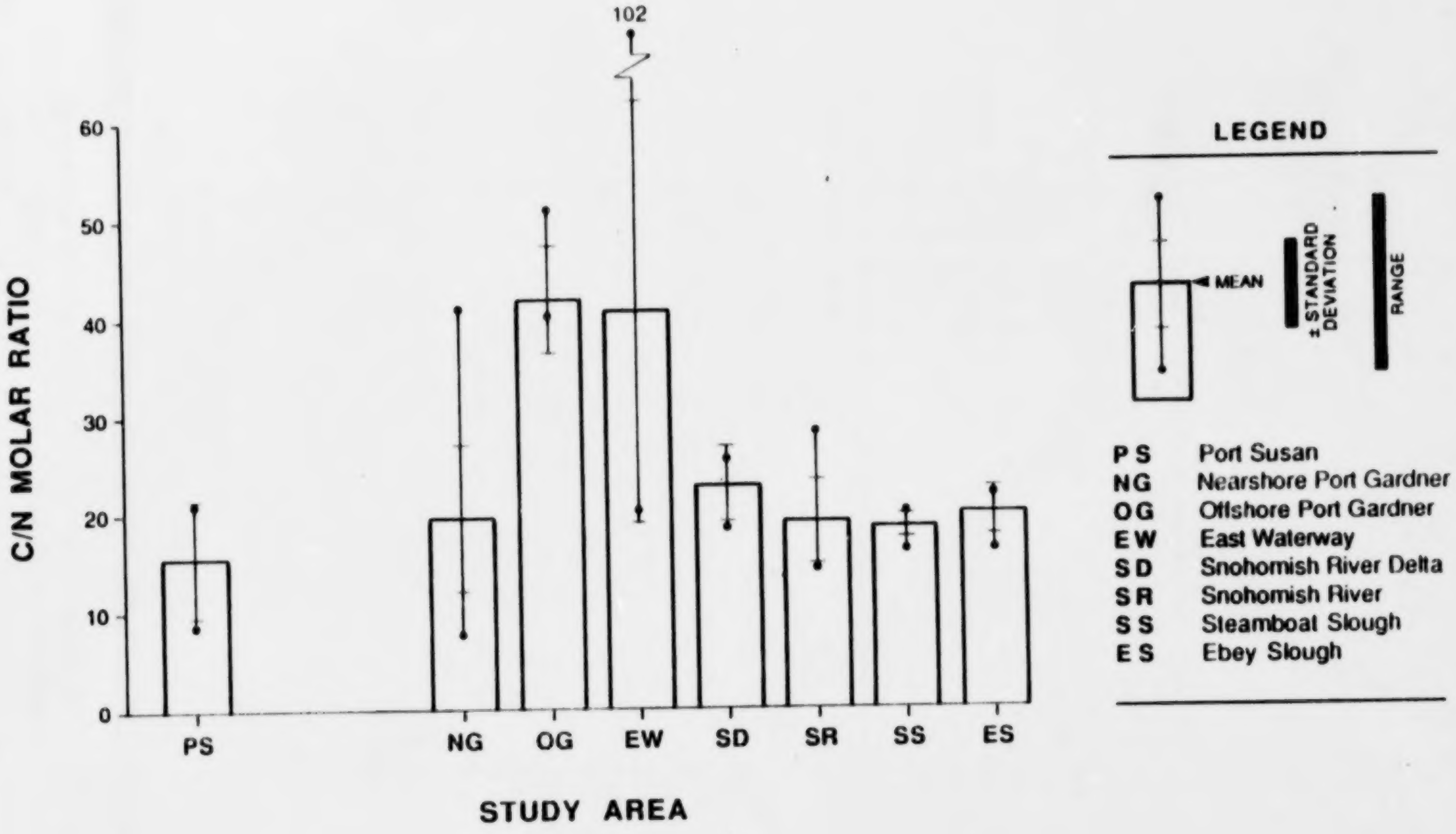


Figure 11. Average carbon/nitrogen (C/N) molar ratios in sediments from all study areas.

approximately 7, soil and particulate material in rivers have C/N ratios of 10 to 15, and woods have considerably higher C/N ratios (e.g., between 150 and 550; Hedges et al. 1985, 1986). Average C/N ratios were relatively consistent (between 15 and 25) among Everett Harbor study areas except for East Waterway and offshore Port Gardner, which had average molar C/N ratios of approximately 40. Two stations in the East Waterway, EW-04 and EW-13, exhibited anomalously high C/N ratios (69 and 100, respectively). These elevated ratios are consistent with pulp mill activities in this area, although other source materials (e.g., coals) also have relatively high C/N ratios.

Sulfides--

The distribution of water-soluble sulfide concentrations in sediments is summarized in Figure 12. Because sulfide is indicative of sulfate-reducing (poorly oxygenated) conditions, it is common for sulfide levels to be high in areas that are rich in organic material and high in oxygen demand. In general, this relationship was observed in this study. The correlation between TOC and sulfides was moderate ($r=0.61$, $n=60$, $P<0.05$). Mean sulfide concentrations in Port Susan and throughout most of the study areas were relatively low (<120 mg/kg DW). The highest mean (3,000 mg/kg DW) and individual (11,000 mg/kg DW) sulfide concentrations were found in the East Waterway. The highest sulfide concentration at an individual station outside of the East Waterway was 600 mg/kg DW observed at Station SR-07 in the Everett marina.

A more detailed summary of sulfide concentrations in the East Waterway is presented in Figure 13. With the exception of Station EW-01, sediments near the head of the waterway contained the highest sulfide concentrations. The undetected sulfide value reported at Station EW-01 (detection limit = 20 mg/kg DW) is probably an analytical error, based upon an observation of an extremely strong sulfur odor that was recorded in field notes during sample collection and processing. Sulfide concentrations decreased toward the mouth of the waterway. The discharge of sulfite pulp wastes in the East Waterway and sulfur-rich discharges from a storm drain in the northeast corner of the waterway are probably important sources of sulfur and relatively high oxygen demand in this area (particularly at the head of the waterway).

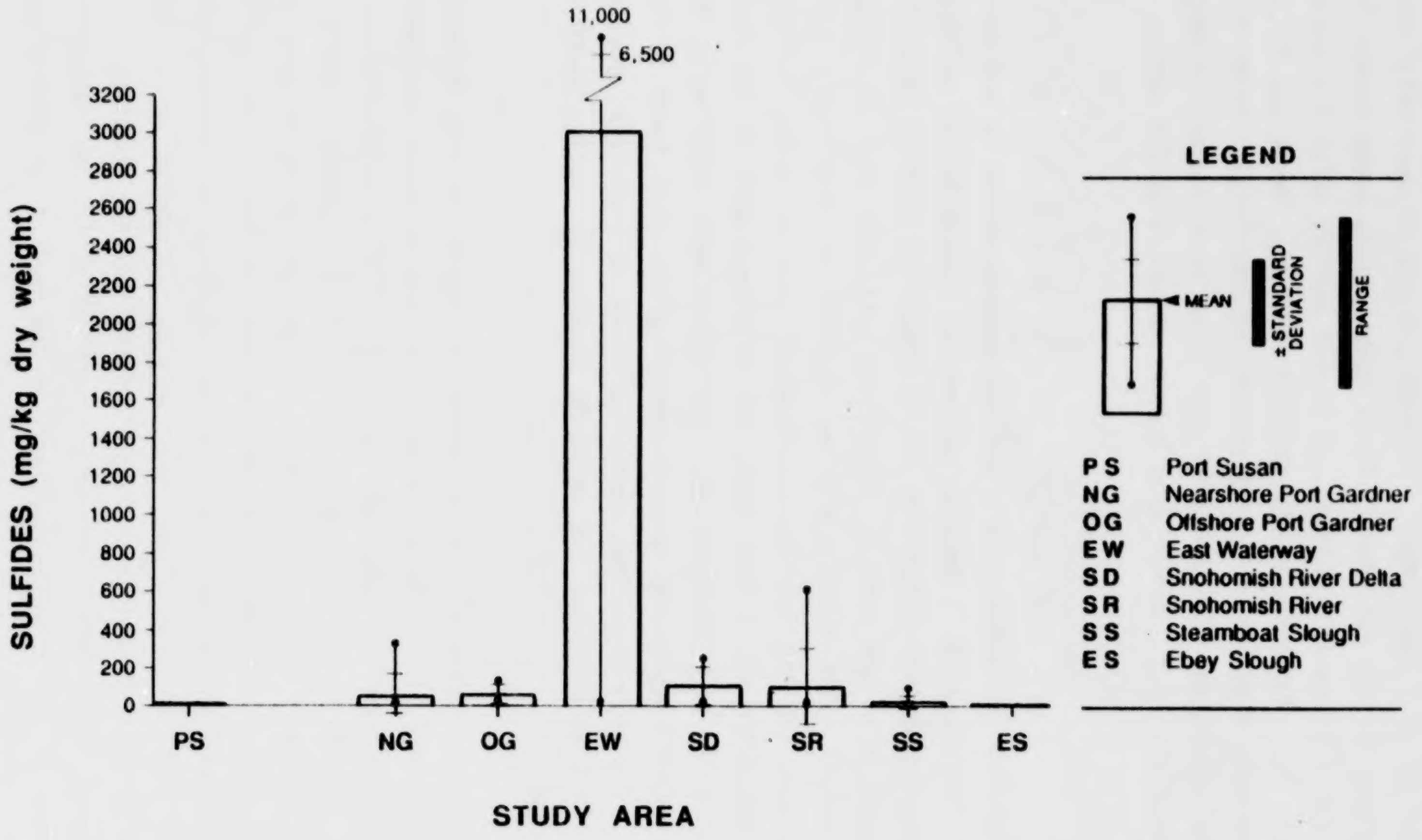


Figure 12. Average sulfide concentrations (mg/kg dry weight) in sediments from all study areas.

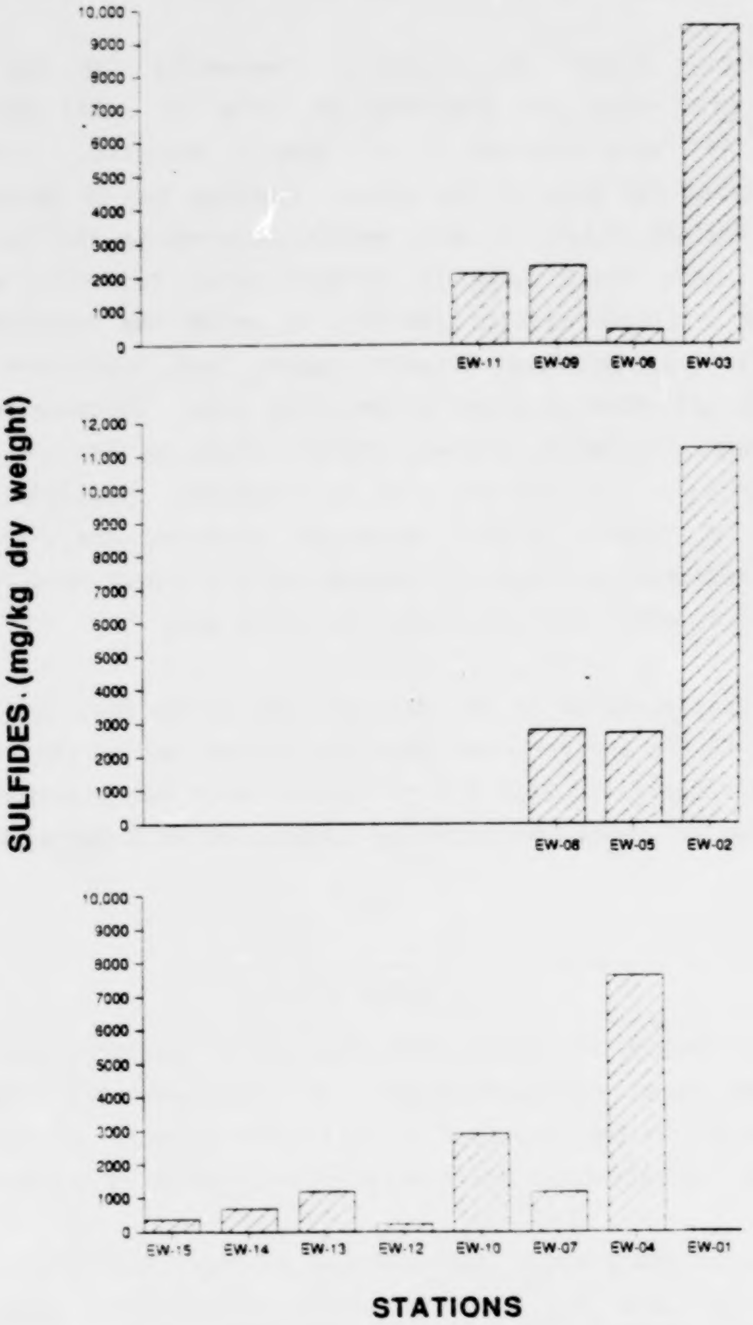


Figure 13. Sulfide concentrations (mg/kg dry weight) in sediments of the East Waterway.

Sediment Chemistry: Metals

Concentration ranges and detection frequencies for the 14 metals analyzed in this study are presented in Table 14. All metals except selenium and TBT were detected in all samples analyzed. Concentration ranges were broad for many of the metals, spanning two to three orders of magnitude. Maximum values of most metals occurred in the East Waterway (Table 14). This broad range in sediment metal concentrations can be attributed to a single station (EW-14), at which the concentrations of several metals (i.e., antimony, arsenic, copper, lead, zinc) were 5-25 times higher than at all other stations in the study area. Chromium and selenium were exceptions, displaying maximum concentrations at Stations NG-15 and NG-01, respectively. Nickel was also an exception, displaying a maximum concentration at Station SR-07. Chromium, selenium, and nickel concentrations at these stations were not substantially elevated relative to their concentrations at other stations within the study area.

TBT was only measured at two stations, one in the Port Susan reference area (Station PS-02) and the other near the Everett marina (Station SR-07). The estimated concentration of TBT at Station SR-07 was elevated above the single measured reference concentration (undetected at 0.006 mg/kg DW) by a factor of 15.

Sediment Metals of Concern--

Metals of concern are metals that occurred at concentrations exceeding those in Puget Sound reference areas. It is assumed that the range of reference concentrations provides a reasonable measure of the possible variability of concentrations in relatively uncontaminated sediments.

The range of trace metal concentrations in Puget Sound reference areas is summarized in Table 15. Metal concentrations from Port Susan sediments collected for this study (Stations PS-02 to PS-04) are included among the reference values summarized in Table 15. Metals concentrations at Port Susan stations (1986 data) were within the ranges observed for other Puget Sound reference areas.

TABLE 14. CONCENTRATIONS OF METALS AND TRIBUTYLTIN IN SURFACE SEDIMENTS OF EVERETT HARBOR AND PORT SUSAN

Chemical	Range (mg/kg dry wt)	Detection Frequency	Location of Maximum
Antimony	E1.21 - E203	54/54	EW-14
Arsenic	2.62 - 685	54/54	EW-14
Cadmium	0.04 - 7.94	54/54	EW-14
Chromium	51 - 271	54/54	NG-15
Copper	10.6 - 1,010	54/54	EW-14
Iron	16,600 - 90,600	54/54	EW-14
Lead	4.4 - 517	54/54	EW-14
Manganese	282 - 1,050	54/54	EW-14
Mercury	0.006 - 0.776	54/54	EW-14
Nickel	24.1 - 69[a]	54/54	SR-07
Selenium	U0.20 - 0.58[a]	17/54	NG-01
Silver	0.007 - 1.03[a]	54/54	EW-14
Zinc	38 - 5,910	54/54	EW-14
Tributyltin	U0.006 - 0.093	1/2	SR-07

[a] Maximum observed concentration in this study does not exceed the maximum concentration observed among Puget Sound reference areas.

TABLE 15. SUMMARY OF METAL CONCENTRATIONS IN SEDIMENTS FROM PUGET SOUND REFERENCE AREAS

Chemical	Range (mg/kg dry wt)[a]	Detection Frequency	Reference Sites[b]
Antimony	U0.1[c]-2.79 (E1.52[c]-E2.18)	19/39	1,2,3,4,7,8,9,10,11
Arsenic	1.9-17 (6.7-10.1)	41/41	1,2,3,4,7,8,9,10,11
Cadmium	0.047-1.9 (0.047-0.082)	31/31	1,2,3,4,6,9,10,11
Chromium	9.6-E255 (89-232)	45/45	1-11
Copper	5-74 (13.6-16.7)	35/35	1,2,3,4,5,6,9,10,11
Lead	U0.1-24 (5.6-10.9)	28/35	1,2,3,4,5,6,9,10,11
Mercury	0.01-0.28 (0.029-0.056)	45/45	1-11
Nickel	4-140 (41.3-65)	33/33	1,2,3,4,5,9,10,11
Selenium	U0.1-1.0 (0.27-0.40)	21/31	1,2,3,4,6,9,10,11
Silver	U0.02-3.3 (0.020-0.027)	31/33	1,2,3,4,5,9,10,11
Zinc	15-E102 (39.1-51.5)	33/33	1,2,3,4,5,9,10,11

[a] The range of Port Susan concentrations from this study (Stations PS-02 to PS-04) is shown in parentheses.

[b] Reference sites:
1. Carr Inlet
2. Samish Bay
3. Dabob Bay
4. Case Inlet
5. Port Madison
6. Port Susan
7. Nisqually Delta
8. Hood Canal
9. Sequim Bay
10. Port Susan (1985)
11. Port Susan (1986)

[c] U = Undetected at the detection limit shown.
E = Estimated value.

References:

(Site 1) Tetra Tech (1985a); Crecelius et al. (1975)
(Site 2) Battelle (1986)
(Site 3) Battelle (1986)
(Site 4) Crecelius et al. (1975); Malins et al. (1980)
(Site 5) Malins et al. (1980)
(Site 6) Malins et al. (1982)
(Site 7) Crecelius et al. (1975)
(Site 8) Crecelius et al. (1975)
(Site 9) Battelle (1986)
(Site 10) PTI and Tetra Tech (1988)
(Site 11) This study.

Eight of eleven EPA priority pollutant metals analyzed in this study had concentrations exceeding the highest Puget Sound reference concentrations and are thus of concern. Nickel, selenium, and silver concentrations did not exceed Puget Sound reference area values, and are thus not considered of concern in this study. Chromium will not be considered further because only one station (NG-15) had a chromium concentration that exceeded the maximum Puget Sound reference concentration, and it exceeded it by only 17 percent. In addition to the EPA priority pollutant metals, TBT exceeded the single reference area measurement at the single study area station at which it was measured. The limited number of samples tested for TBT does not allow for interpretation of spatial distributions.

A summary of the distributions of the metals of concern is presented in Table 16. In this table, EAR are used to describe chemical distributions. An EAR is the ratio of the dry weight concentration of a chemical divided by the average concentration determined for six Carr Inlet stations (Tetra Tech 1985a). Threshold EAR values (Table 16) are the EAR equivalent of the maximum concentration in Puget Sound reference areas. Thus, EAR values above the threshold value indicate exceedance of the maximum Puget Sound reference concentration. The threshold EAR value is exceeded by a factor of 10 only at Station EW-14. The most elevated concentrations for all metals of concern were observed in the East Waterway, at Station EW-14 (Table 16). Also shown in Table 16 is the maximum EAR excluding Station EW-14. With this station excluded, the maximum concentrations measured in the study area for metals of concern (except antimony) were elevated above threshold EAR values by a factor of less than 4.

Mean EAR values for metals of concern in Everett Harbor study areas are illustrated in Figure 14. The mean EAR values for the East Waterway including Station EW-14 are denoted with a dashed line (Figure 14). Cadmium and mercury concentrations exceeded maximum reference concentrations at only four stations, all located in the East Waterway (maximum EAR values for cadmium and mercury were 8.4 and 19, respectively). Copper concentrations exceeded maximum reference concentrations in the East Waterway and at Station SR-07 in the Snohomish River. Lead concentrations exceeded maximum reference concentrations in the East Waterway, at Station SR-07, and at

TABLE 16. RANGE IN EAR FOR METALS OF CONCERN IN SEDIMENTS OF EVERETT HARBOR AND PORT SUSAN

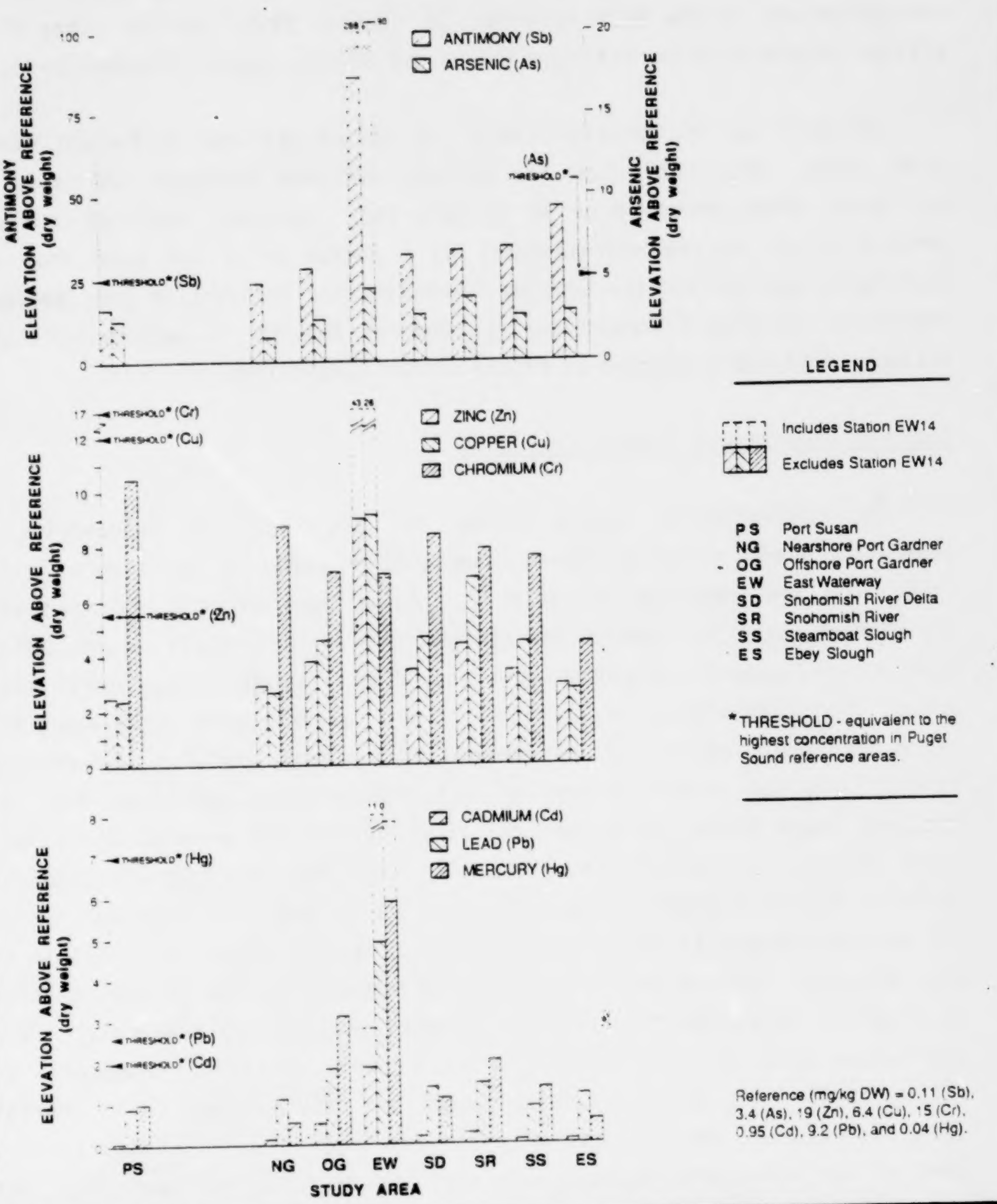
Chemical	EAR[a] Range[b]	EAR[a] Median	EAR[a] Threshold[c]	Areas where Threshold Exceeded by 10 Times[d]
Antimony	11-1,850 (240)	29	25	EW-14
Arsenic	0.78-203 (8.0)	2.4	5.0	EW-14
Cadmium	0.04-8.4 (4.8)	0.14	2.0	--
Chromium	3.4-18 (18)	7.3	17	--
Copper	1.7-160 (15)	3.8	12	EW-14
Lead	0.48-56 (9.6)	1.2	2.6	EW-14
Mercury	0.15-19 (12)	1.2	7.0	--
Zinc	2.0-310 (14)	3.2	5.4	EW-14

[a] Dry-weight concentration in study area sediments divided by the average concentration measured in six Carr Inlet sediments (Tetra Tech 1985a).

[b] Value in parentheses is the maximum EAR value excluding Station EW-14.

[c] The threshold EAR is defined as the ratio of the maximum reference sediment concentration in Puget Sound divided by the average for six Carr Inlet reference sediments. Above the threshold EAR, the dry-weight concentration of a study area sediment contaminant would exceed the maximum concentration reported for any Puget Sound reference site listed in Table 15.

[d] The contaminant EAR values for the listed stations exceeded the threshold level by at least one order of magnitude. The factor of 10 was arbitrary, but was useful for indicating the areas of greatest contamination. Sediments from the underlined stations had the highest observed concentrations.



*THRESHOLD - equivalent to the highest concentration in Puget Sound reference areas.

Reference (mg/kg DW) = 0.11 (Sb), 3.4 (As), 19 (Zn), 6.4 (Cu), 15 (Cr), 0.95 (Cd), 9.2 (Pb), and 0.04 (Hg).

Figure 14. Mean EAR of metals of concern from all study areas.

Station ES-01. Zinc and arsenic concentrations exceeded maximum reference concentrations in the East Waterway, at Station SR-07 and two other fine-grained Snohomish River stations (SR-04 and SR-05), and at Station ES-01.

Antimony had the greatest EAR of all metals measured in Everett Harbor study areas. Mean EAR values for antimony exceeded threshold EAR values in all study areas except Area NG (Figure 14). However, reported antimony concentrations may be overestimates by a factor of 5 and were thus not considered appropriate for problem identification and ranking (see **Sediment Chemistry, Quality Assurance/Quality Control Results** in **Methods** section). Antimony data are presented in Figure 14 for comparative purposes.

Sediment Chemistry: Organic Compounds

The concentration ranges (ug/kg DW) and detection frequencies of semivolatile and volatile organic compounds detected at least once in the study area are presented in Table 17. Among those organic compounds with the highest detection frequencies and reported at the highest concentrations were 4-methylphenol, dehydroabietic and abietic acids (among other resin acids), PAH (naphthalene in particular), and several tentatively identified compounds (most notably, a diterpenoid hydrocarbon, possibly dehydroabietane). Maximum concentrations of all EPA priority pollutant PAH, all measured resin acids, phenol and all alkyl-substituted phenols, all chlorinated phenols, all chlorinated guaiacols, PCBs, most TIO compounds, and all detected volatile organic compounds occurred in the East Waterway, as did the maximum concentrations of most metals of concern (Table 17). Within the East Waterway, maximum concentrations of a number of compounds were observed at Stations EW-01 (particularly chlorinated phenols and guaiacols), EW-04 (including certain resin acids, certain phenols, most TIO compounds, and PCBs), EW-07 (most notably 4-methylphenol and naphthalene), EW-13 (certain resin acids), and EW-14 (especially PAH and benzoic acid). Structures of some of the compounds listed in Table 17 are depicted in Figure 15. Note that some TIO compounds were identified by mass spectral characteristics (e.g., base peak m/z 181) or structural characteristics deduced from mass spectra (e.g., compound class); these compounds will be described in more detail later in this section.

TABLE 17. CONCENTRATIONS OF DETECTED SEMIVOLATILE AND
VOLATILE ORGANIC COMPOUNDS IN SURFACE SEDIMENTS
OF EVERETT HARBOR AND PORT SUSAN[a]

Chemical	Range (ug/kg dry wt)[b]	Detection Frequency	Location of Maximum
LPAH	L36 - 28,000	54/54	EW-14
naphthalene	B3 - X17,000	46/54	EW-07
acenaphthylene	1 - 800	41/54	EW-14
acenaphthene	2 - 5,200	45/54	EW-14
fluorene	6 - 4,300	24/54	EW-14
phenanthrene	3 - 8,100	50/54	EW-04
anthracene	1 - 6,100	51/54	EW-14
HPAH	L36 - 23,000	54/54	EW-14
fluoranthene	3 - 3,700	53/54	EW-13
pyrene	3 - 5,500	49/54	EW-14
benz(a)anthracene	1 - 3,200	54/54	EW-14
chrysene	1 - 3,200	54/54	EW-14
benzofluoranthenes	5 - 4,100	48/54	EW-14
benzo(a)pyrene	1 - 1,700	50/54	EW-14
indeno(1,2,3-c,d)pyrene	1 - 730	42/54	EW-14
dibenzo(a,h)anthracene	2 - 270	29/54	EW-14
benzo(g,h,i)perylene	3 - 550	46/54	EW-14
Total PCBs	U1 - E9,600	7/54	EW-04
Resin Acids			
abietic acid	U130 - 98,000	21/31	EW-13
dehydroabietic acid	E20 - 83,000	29/31	EW-04
12-chlorodehydroabietic acid	E61 - 11,000	19/31	EW-04
14-chlorodehydroabietic acid	E46 - 3,400	10/31	EW-04
dichlorodehydroabietic acid	U130 - E710	5/31	EW-04
isopimaric acid	E85 - E11,000	20/31	EW-13
neoabietic acid	E79 - E14,000	8/31	EW-13
sandaracopimaric acid	E17 - 14,000	21/31	EW-01
Phenols and Guaiacols			
phenol	11 - 2,900	49/54	EW-10
2-methylphenol	6 - 1,200	3/54	EW-04
4-methylphenol	3 - X98,000	50/54	EW-07
2,4-dimethylphenol	U10 - 520	2/54	EW-04
2-chlorophenol	E1 - 160	11/60	EW-04
2,4-dichlorophenol	2 - 320	21/60	EW-01
2,4,6-trichlorophenol	U2 - 290	22/60	EW-01
2,4,5-trichlorophenol	E1 - 120	18/60	EW-02
2,3,4,6-tetrachlorophenol	U2 - 120	6/31	EW-01
pentachlorophenol	U2 - E460	22/60	EW-04
3,4,5-trichloroguaiacol	E1 - 110	11/31	EW-01
4,5,6-trichloroguaiacol	U2 - 48	6/31	EW-01
tetrachloroguaiacol	U2 - 50	4/31	EW-01
Chlorinated Benzenes			
1,2-dichlorobenzene	7 - 96	4/54	EW-04
1,4-dichlorobenzene	2 - 25[c]	14/54	OG-02
Phthalates			
dimethyl phthalate	8 - 26[c]	2/54	NG-02
diethyl phthalate	3 - 11[c]	5/54	NG-02, SD-03
di-n-butyl phthalate	B10 - 260[c]	20/54	EW-13
butyl benzyl phthalate	U10 - 70	6/54	EW-01
bis(2-ethylhexyl)phthalate	B10 - 930	39/54	EW-14
di-n-octyl phthalate	B3 - 4[c]	3/54	SR-02, SR-03

TABLE 17. (Continued)

Chemical	Range (ug/kg dry wt)[b]	Detection Frequency	Location of Maximum
Pesticides			
lindane (gamma-HCH)	U0.5 - 1[c]	1/54	NG-04
p,p'-DDT	U1 - 23	1/54	SD-03
Nitrogen-Containing Compounds			
N-nitrosodiphenylamine	8 - 57	13/54	EW-01
Miscellaneous Extractables and Tentatively Identified Compounds			
benzyl alcohol	U10 - 810	6/54	EW-04
benzoic acid	E10 - 5,900	25/54	EW-14
dibenzofuran	3 - 5,000	44/54	EW-14
2-methylnaphthalene	2 - 7,400	38/54	EW-07
1-methylpyrene[d]	U - E240	25/54	NG-11
retene[d]	U - E3,100	44/54	EW-04
cymene (unspecified isomer)[d]	U - E2,900	41/54	EW-04
dibenzothiophene[d]	U - E280	19/54	EW-14
1,2,4-trithiolane[d]	U - E5,800	31/54	EW-04
diterpenoid hydrocarbon[d] (base peak 255)	U - E23,000	41/54	EW-04
diterpenoid alcohol[d] (base peak 271)	U - E8,600	42/54	EW-11
hexadecanoic acid[d]	U - E2,300	27/54	EW-10
hexadecanoic acid methyl ester[d]	U - E4,300	53/54	EW-04
hexadecenoic acid methyl ester[d]	U - E3,200	53/54	EW-04
cholesterol[d]	U - E630	51/54	EW-04
campesterol[d]	U - E1,100	20/54	EW-04
alkanol (unidentified)[d]	U - E2,200	43/54	EW-04
base peak 181, isomer #1[d]	U - E12,000	44/54	EW-04
base peak 181, isomer #2[d]	U - E6,500	45/54	EW-04
Volatile Organic Compounds			
acetone	U6 - 230	4/19	EW-05
ethylbenzene	U3 - E5[c]	2/19	EW-09
total xylenes	U3 - 39	4/19	EW-08

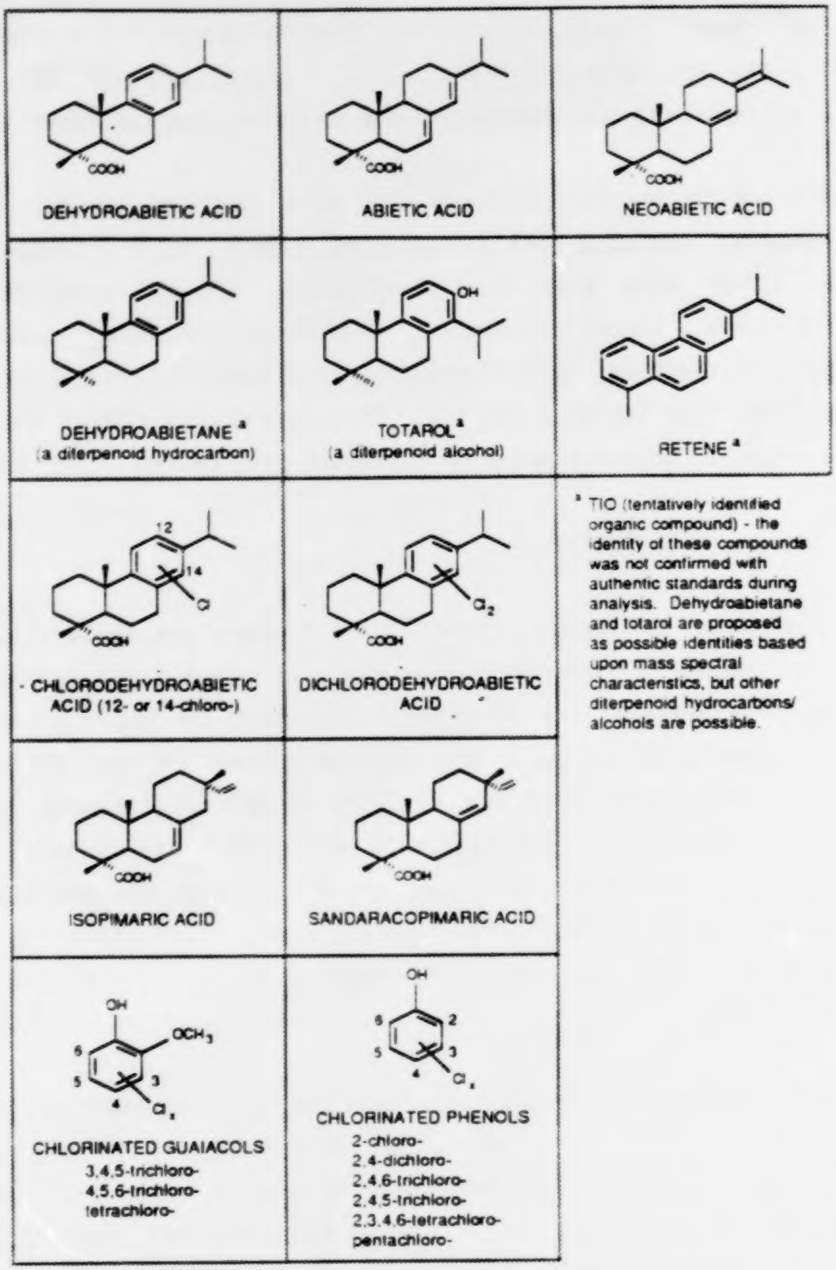
[a] Qualifiers:

U = Substance undetected at the detection limit shown.
B = Blank corrected down to the detection limit shown.
X = The surrogate recovery for this compound was low (<10 percent). Hence, the recovery correction was at least a factor of 10.
L = "Less than" - the reported concentration is the mean of a detected value and a detection limit or, for PAH sums, the sum includes detection limits.
E = Estimated value.

[b] Maximum is the highest detected value even if maximum detection limits were higher.

[c] Maximum concentration does not exceed Puget Sound reference area concentrations.

[d] Tentatively identified organic (TIO) compound - detection limits for TIO compounds were not assigned.



DEHYDROABIETIC ACID

ABIETIC ACID

NEOABIETIC ACID

DEHYDROABIETANE [a]
(a diterpenoid hydrocarbon)

TOTAROL [a]
(a diterpenoid alcohol)

RETENE [a]

CHLORODEHYDROABIETIC ACID (12- or 14-chloro-)

DICHLORODEHYDROABIETIC ACID

ISOPIMARIC ACID

SANDARACOPIMARIC ACID

CHLORINATED GUAIACOLS
3,4,5-trichloro-
4,5,6-trichloro-
tetrachloro-

CHLORINATED PHENOLS
2-chloro-
2,4-dichloro-
2,4,6-trichloro-
2,4,5-trichloro-
2,3,4,6-tetrachloro-
pentachloro-

[a] TIO (tentatively identified organic compound) - the identity of these compounds was not confirmed with authentic standards during analysis. Dehydroabietane and totarol are proposed as possible identities based upon mass spectral characteristics, but other diterpenoid hydrocarbons/ alcohols are possible.

Figure 15. Structures of selected organic compounds observed in sediments.

Several semivolatile organic compounds were detected infrequently (three or fewer times), including 2-methylphenol, 2,4-dimethylphenol, dimethyl phthalate, di-n-octyl phthalate, lindane, and p,p'-DDT. The three detected volatile organic compounds were detected four or fewer times.

Semivolatile organic compounds that were searched for but not detected in any samples included all halogenated ethers, all nitrogen-containing compounds other than N-nitrosodiphenylamine, 1,3-dichlorobenzene, 1,2,4-trichlorobenzene, hexachlorobenzene, 2-chloronaphthalene, hexachlorobutadiene, hexachloroethane, hexachlorocyclopentadiene, 4-chloro-3-methylphenol, and isophorone (see Tables 1 and 17). Most target chlorinated pesticides and volatile organic compounds were not detected (see Tables 1 and 17).

Organic Compounds of Concern--

As described for metals, chemicals of concern are those chemicals that occur at concentrations exceeding the range of Puget Sound reference areas. The range of concentrations of organic compounds in Puget Sound reference areas are summarized in Table 18. Concentrations in Port Susan sediments analyzed for this study (Stations PS-02 to PS-04) are included in Table 18. Port Susan concentrations were typically well within the range of concentrations for other Puget Sound reference areas, although the maximum 4-methylphenol concentration in Port Susan (290 ug/kg DW) (this study) was considerably higher than the maximum value reported in Carr Inlet (32 ug/kg DW) (Tetra Tech 1985a).

Organic compounds that did not exceed the range of Puget Sound reference concentrations in this study were 1,4-dichlorobenzene, dimethyl phthalate, diethyl phthalate, di-n-butyl phthalate, di-n-octyl phthalate, lindane, and ethylbenzene (Tables 17 and 18). These compounds are thus of relatively minor concern and will not be discussed further.

Distributions of contaminants of concern are summarized in terms of EAR values in Table 19. Summaries of distributions of organic chemicals with EAR >1,000 are presented in Table 20. The distributions of organic chemicals of concern are summarized below.

TABLE 18. SUMMARY OF ORGANIC COMPOUND CONCENTRATIONS IN SEDIMENTS FROM PUGET SOUND REFERENCE AREAS[a]

Chemical	Range (ug/kg dry wt)[b]	Detection Frequency	Reference Sites[c]
LPAH	4-L71 (L36-L42)	13/13	1,8,9
naphthalene	U0.5-U40 (B3-U10)	12/27	1,2,3,4,5,6,8,9
acenaphthylene	U0.1-U40 (1-U10)	2/27	1,2,3,4,5,6,8,9
acenaphthene	U0.1-U40 (U10)	4/27	1,2,3,4,5,6,8,9
fluorene	U0.1-40 (U10)	7/28	All
phenanthrene	4-170 (4-7)	18/24	1,2,3,6,7,8,9
anthracene	U0.5-U40 (1-2)	11/24	1,2,3,6,7,8,9
HPAH	34-L100 (L36-L48)	13/13	1,8,9
fluoranthene	5-100 (5-7)	24/29	All
pyrene	5-120 (5-7)	23/29	All
benz(a)anthracene	2-U40 (2-3)	15/24	1,2,3,6,7,8,9
chrysene	4-U40 (4-5)	15/24	1,2,3,6,7,8,9
benzo(b)fluoranthene	U5-94	15/25	1,2,3,4,5,6,7,8
benzo(k)fluoranthene	E4.8-94	15/25	1,2,3,4,5,6,7,8
benzo(a)pyrene	U0.37-40 (1-3)	16/21	1,3,4,5,6,7,8,9
indeno(1,2,3-c,d)pyrene	U0.37-30 (1-U10)	10/19	1,4,5,6,7,8,9
dibenzo(a,h)anthracene	U0.4-E10 (2-U10)	3/12	1,8,9
benzo(g,h,i)perylene	E1.2-20 (3-4)	8/13	1,7,8,9
Total PCBs	3.1-U50[d] (U50)	7/22	1,2,3,4,6,7,9
Resin Acids			
abietic acid	U130-U180	0/3	9
dehydroabietic acid	E20-U130	2/3	9
12-chlorodehydroabietic acid	U130-U180	0/3	9
14-chlorodehydroabietic acid	U130-U180	0/3	9
dichlorodehydroabietic acid	U130-U180	0/3	9
isopimaric acid	U130-U180	0/3	9
neoabietic acid	U130-U180	0/3	9
sandaracopimaric acid	U130-U180	0/3	9
Phenols and Guaiacols			
phenol	U0.5-62[e] (Z100-Z200)	5/17	1,2,3,8
2-methylphenol	U0.7-U50 (U20-U50)	0/11	--
4-methylphenol	U0.8-290 (84-290)	7/11	1,8,9
2,4-dimethylphenol	U1-U14 (U10)	0/13	1,8,9
2-chlorophenol	U0.5-U9.4 (U3)	0/13	1,8,9
2,4-dichlorophenol	U0.5-U43 (U3)	0/13	1,8,9
2,4,6-trichlorophenol	U0.5-U38 (E2-L3)	2/13	1,8,9
2,4,5-trichlorophenol	U3-U37 (U3-L3)	1/11	1,8,9
2,3,4,6-tetrachlorophenol	U3	0/3	9
pentachlorophenol	0.1-U50[d] (U3)	1/10	1,8,9
3,4,5-trichloroguaiacol	U3	0/3	9
4,5,6-trichloroguaiacol	U3	0/3	9
tetrachloroguaiacol	U3	0/3	9
Chlorinated Benzenes			
1,4-dichlorobenzene	U0.06-U40[d] (U10)	1/23	1,2,3,4,5,8,9
1,2-dichlorobenzene	U0.06-U40[d] (U10)	1/22	1,2,3,4,5,8,9
Phthalate Esters			
dimethyl phthalate	U0.5-U50 (U10)	1/12	1,8,9
diethyl phthalate	4-18 (U10)	4/8	1,9
di-n-butyl phthalate	U20-760 (B10)[f]	3/5	1
butyl benzyl phthalate	U0.5-U25 (U10)	3/12	1,8,9
bis(2-ethylhexyl)phthalate	U0.5-U25 (B10-Z58)[f]	0/5	1
di-n-octyl phthalate	U0.5-E56 (B3-U10)	4/12	1,8,9

TABLE 18. (Continued)

Chemical	Range (ug/kg dry wt)[b]	Detection Frequency	Reference Sites[c]
Pesticides			
p.p'-DDT[g]	U1.0-U10 (U1-U10)	0/12	1,8,9
lindane (gamma-HCH)	U0.5-U50 (U0.5-U50)	0/9	1,8,9
Miscellaneous Extractables			
benzyl alcohol	U3.4-U20[d] (U20-U200)	0/6	1,9
benzoic acid	U7.2-430[d] (E10-U100)	4/6	1,8,9
dibenzofuran	U5-E14 (U10-11)	4/11	1,8,9
2-methylnaphthalene	E0.3-U22 (2-U10)	10/17	1,4,5,6,8,9
1-methylpyrene[h]	U	0/3	9
retene[h]	U-E130 (U-1.6)	8/13	1,8,9
cymene[h]	U-12	1/4	1,9
dibenzothiophene[h]	U	0/3	9
1,2,4-trithiolane[h]	U	0/3	9
diterpenoid hydrocarbon[h]	U	0/3	9
diterpenoid alcohol[h]	E1.2-E3.1	3/3	9
hexadecanoic acid[h]	U-E35	1/3	9
hexadecanoic acid methyl ester[h]	E380-E480	3/3	9
hexadecenoic acid methyl ester[h]	E330-E380	3/3	9
cholesterol[h]	E19-E37	3/3	9
campesterol[h]	U	0/3	9
alkanol[h]	U	0/3	9
base peak 181, isomer #1[h]	U	0/3	9
base peak 181, isomer #2[h]	U	0/3	9
Nitrogen-Containing Compounds			
N-nitrosodiphenylamine	U0.5-U10 (U10)	0/8	1,9
Volatile Organic Compounds			
acetone	U6	0/3	9
ethylbenzene	U3-U16 (U3)	0/11	2,3,9
total xylenes	U3	0/3	9

[a] This table includes only chemicals that were detected in the present study.

Qualifiers:

L = "Less than" - the reported concentration is the mean of a detected value and a detection limit or, for PAH sums, the sum includes detection limits.
U = Undetected at the detection limit shown.
E = Estimated value.
B = Blank-corrected down to the detection limit shown.
Z = Value is blank-corrected but exceeds detection limit.

[b] The range of Port Susan concentrations from this study (Stations PS-02, PS-03, and PS-04) is in parentheses.

[c] Reference sites:
1. Carr Inlet
2. Samish Bay
3. Dabob Bay
4. Case Inlet
5. Port Madison
6. Port Susan
7. Nisqually Delta
8. Port Susan (1985)
9. Port Susan (1986, this study)

[d] Detection limits for this chemical or chemical group that exceeded 50 ug/kg have been excluded for the purpose of reference area comparisons; this is consistent with treatment of reference area data in Tetra Tech (1985a).

[e] An anomalously high phenol value of 1,800 ug/kg dry wt was found at one Carr Inlet station (Tetra Tech 1985a). For the purpose of reference area comparison, this value has been excluded. Data from Port Susan (this study) were excluded because laboratory contamination of phenol was observed during analysis of these reference area samples.

TABLE 18. (Continued)

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[f] Data from Port Susan (this study) were excluded because laboratory contamination of this phthalate was observed during analysis of these reference area samples.

[g] Higher detection limits for single component pesticides (U25) were reported for Main Sediment Quality Survey samples from Carr Inlet in Tetra Tech (1985a). However, these detection limits were based on GC/MS analysis, which is less sensitive than GC/ECD and was considered undesirable for characterizing reference areas. GC/ECD analyses for Carr Inlet samples in the Preliminary Survey (Tetra Tech 1985a) were consistent with the U10 value.

[h] Tentatively identified organic compound. Detection limits were not assigned when tentatively identified compounds were not found during mass spectral searches of reference sample extracts.

References:

(Site 1) Tetra Tech (1985a); Mowrer et al. (1977)
(Site 2) Battelle (1986)
(Site 3) Battelle (1986); Prahl and Carpenter (1979)
(Site 4) Malins et al. (1980); Mowrer et al. (1977)
(Site 5) Malins et al. (1980)
(Site 6) Malins et al. (1982)
(Site 7) Barrick and Prahl (1987); Mowrer et al. (1977)
(Site 8) PTI and Tetra Tech (1988); Stations PS-01 through PS-04
(Site 9) This study.

TABLE 19. RANGE IN EAR FOR ORGANIC COMPOUNDS OF CONCERN IN SEDIMENTS OF EVERETT HARBOR AND PORT SUSAN[a]

	EAR[b]			
Chemical	Range	Median[c]	Threshold[d]	Areas where Threshold Exceeded by 10 Times[e]
LPAH	0.88 - 690	6.4	1.7	EW,NG,OG, SR
HPAH	0.46 - 290	4.1	1.3	EW,NG, SR
Total PCBs	0.17 - 1,600	0.83	8.3	EW,NG
Resin Acids				
abietic acid	0.87 - 650	15	1.2	EW,SR
dehydroabietic acid	0.32 - 1,300	22	2.1	EW,OG,SR
12-chlorodehydroabietic acid	0.41 - 73	5.2	1.2	EW
14-chlorodehydroabietic acid	0.31 - 23	4.0	1.2	EW
dichlorodehydroabietic acid	0.87 - 4.7	4.0	1.2	--
isopimaric acid	0.57 - 73	6.2	1.2	EW
neoabietic acid	0.53 - 93	2.7	1.2	EW
sandaracopimaric acid	0.12 - 95	6.4	1.2	EW
Phenols and Guaiacols				
phenol	0.33 - 88	6.8	1.9	ES,EW,NG
2-methylphenol	0.86 - 170	7.1	7.1	EW
4-methylphenol	0.23 - 7,500	57	22	EW,NG
2,4-dimethylphenol	1.5 - 76	7.3	2.1	EW
2-chlorophenol	0.29 - 46	5.7	2.7	EW
2,4-dichlorophenol	0.29 - 47	2.9	6.3	--
2,4,6-trichlorophenol	0.29 - 43	2.9	5.6	--
2,4,5-trichlorophenol	0.1 - 12	1.7	3.7	--
2,3,4,6-tetrachlorophenol	0.67 - 40	1.3	1.0	EW
pentachlorophenol	0.06 - 14	0.6	1.5	--
3,4,5-trichloroguaiacol	0.33 - 37	1.3	1.0	EW
4,5,6-trichloroguaiacol	0.67 - 16	1.5	1.0	EW,SS
tetrachloroguaiacol	0.67 - 17	1.3	1.0	EW
Chlorinated Benzenes				
1,2-dichlorobenzene	2.0 - 27	2.9	11	--
Phthalate Esters				
butyl benzyl phthalate	0.59 - 4.2	0.6	1.5	--
bis(2-ethylhexyl)phthalate	0.60 - 55	2.2	1.5	EW
Pesticides				
p,p'-DDT	0.1 - 2.3	0.1	1.0	--
Miscellaneous Extractables and Tentatively Identified Compounds				
benzyl alcohol	1.0 - 81	2.0	2.0	EW
benzoic acid	0.07 - 41	0.7	3.0	EW
dibenzofuran	0.82 - 1,400	4.8	3.8	EW,NG
2-methylnaphthalene	0.54 - 2,000	5.5	6.0	EW,NG
1-methylpyrene	U^{f} - 12	0.3	1.0	NG
retene	U^{f} - 120	0.84	4.8	EW
cymene (unspecified isomer)	U^{f} - 240	1.3	1.0	EW,NG,OG
dibenzothiophene	U^{f} - 14	0.7	1.0	EW
1,2,4-trithiolane	U^{f} - 290	2.7	1.0	EW
diterpenoid hydrocarbon (base peak 255)	U^{f} - 1,200	2.3	1.0	EW,OG
diterpenoid alcohol (base peak 271)	U^{f} - 4,300	9.3	1.6	ES,EW,NG,SR,SS
hexadecanoic acid	U^{f} - 66	5.1	1.0	EW,NG,OG

TABLE 19. (Continued)

Chemical	EAR[b] Range	EAR[b] Median[c]	EAR[b] Threshold[d]	Areas where Threshold Exceeded by 10 Times[e]
Miscellaneous Extractables and Tentatively Identified Compounds (Continued)				
hexadecanoic acid methyl ester	U[f] - 9.9	1.0	1.1	--
hexadecenoic acid methyl ester	U[f] - 9.2	0.9	1.1	--
cholesterol	U[f] - 22	1.9	1.6	EW
campesterol	U[f] - 55	3.4	1.0	EW
alkanol (unidentified)	U[f] - 110	14	1.0	All (EW)
base peak 181, isomer #1	U[f] - 600	7.0	1.0	EW,OG,SD,SR
base peak 181, isomer #2	U[f] - 330	3.5	1.0	EW,OG,SR
Nitrogen-Containing Compounds				
N-nitrosodiphenylamine	2.0 - 14	2.4	2.4	ES,EW,NG, OG,SD,SS
Volatile Organic Compounds				
acetone	1 - 38	1.7	1.0	EW
total xylenes	1 - 13	1.7	1.0	EW

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[a] Only chemicals with concentrations exceeding Puget Sound reference area levels in at least one sample are included in this table.

[b] Dry weight concentration in study area sediments divided by the average concentration measured in six Carr Inlet samples (Tetra Tech 1985a). For chemicals not measured in Tetra Tech (1985a), such as resin acids, most TIO compounds, and chlorinated guaiacols, data from Port Susan were used. For TIO compounds that were undetected in Port Susan, no detection limits were available. In order to generate EAR values for such compounds, a reference concentration of 20 ug/kg DW was assigned as a reasonable detection limit (i.e., twice the detection limit for many semivolatile organic compounds in Port Susan).

[c] Medians are based on data after exclusion of detection limits >100 ug/kg DW for semivolatile organic compounds and >25 ug/kg DW for pesticides.

[d] The threshold EAR is defined as the ratio of the maximum reference sediment concentration in Puget Sound divided by the average for sediments in Carr Inlet (Tetra Tech 1985a) or Port Susan (see footnote b). Above the threshold EAR, the dry weight concentration of a study area sediment contaminant would exceed the maximum concentration (or detection limit) reported for any Puget Sound reference site listed in Table 18.

[e] The contaminant EAR in sediments from at least one station in each listed area exceeded the threshold level by at least one order of magnitude. The factor of 10 is arbitrary, but is useful for indicating the areas of greatest contamination. It was not used in problem area identification or ranking. Sediments in the underlined areas had the highest observed concentrations.

[f] Detection limits are not reported for TIO compounds. Hence, the lower end of the range is unknown.

TABLE 20. SUMMARY OF ORGANIC COMPOUNDS WITH EAR $\geq$1,000[a]

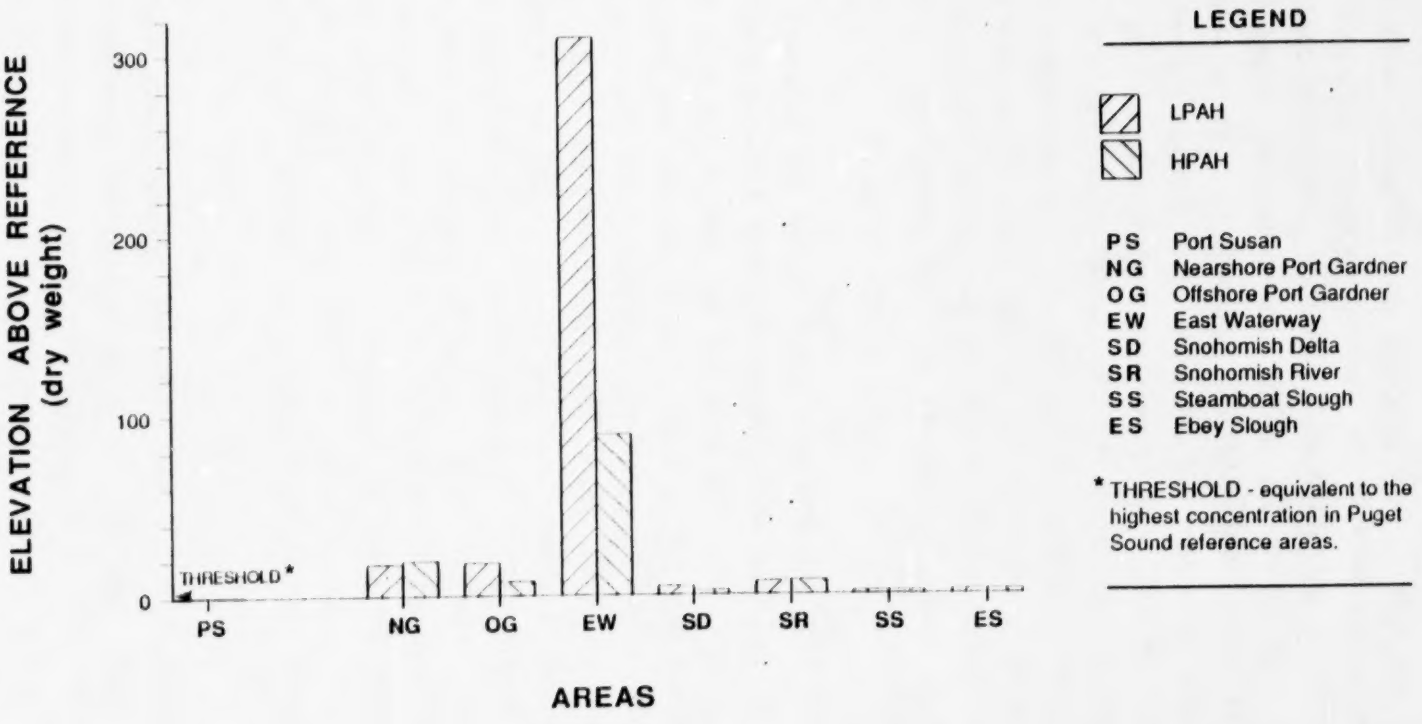
Compound	Station
Naphthalene	EW-04, EW-07, EW-13, EW-14
2-Methylnaphthalene	EW-04, EW-07, EW-13, EW-14
Acenaphthene	EW-14
Fluorene	EW-14
Dibenzofuran	EW-14
Dehydroabietic acid	EW-04, EW-13
4-Methylphenol	EW-04, EW-07, EW-10, EW-13, EW-14
PCBs	EW-04

[a] TIO compounds are not included in this table because of the uncertainty of reference conditions for certain compounds.

Polycyclic Aromatic Hydrocarbons--To facilitate data analysis and to maximize comparability with data analyses performed in other Puget Sound studies, the 16 individual EPA priority pollutant PAH were treated as two groups: LPAH and HPAH. This grouping was considered to be a reasonable data reduction method because the concentrations of individual PAH within each group tended to correlate well. Pearson correlation coefficients (r) among the six LPAH (using dry weight concentrations) ranged from 0.62 to >0.99 with most values exceeding 0.8 (Appendix C). Correlations of naphthalene with other LPAH were typically the least strong. Correlations among HPAH were strong overall, with correlation coefficients ranging from 0.79 to >0.995 with most values exceeding 0.9. Grouping of LPAH and HPAH is also valuable for potential source correlations, as relatively high concentrations of LPAH are typically characteristic of petroleum-derived materials whereas relatively high concentrations of HPAH are more characteristic of combustion-derived materials (e.g., Readman et al. 1982; Prahl and Carpenter 1983; Tetra Tech 1985a).

Mean EAR for LPAH and HPAH were higher in the East Waterway than in any other study area, and LPAH were considerably more elevated than HPAH in the East Waterway (Figure 16). The mean EAR for LPAH in the East Waterway was roughly 310 whereas mean EAR in other study areas were less than 20. Within the East Waterway, LPAH concentrations exceeding EAR of 500 were observed in two areas along the east shore (Stations EW-04 and EW-07, 25,000 and 23,000 ug/kg DW; and Stations EW-13 and EW-14, 24,000 and 28,000 ug/kg DW, respectively) (Figure 17). Concentrations were considerably lower at stations on either side of these two maxima, but EAR for LPAH nonetheless exceeded 100 at Stations EW-10 and EW-15 (Figure 17). PAH concentrations were lower (EAR=59 for LPAH) at Station EW-11 near the west shore of the East Waterway (note that PAH were not analyzed in Samples EW-02, EW-03, EW-05, EW-06, EW-08, and EW-09 because of the availability of recent data; Figure 17).

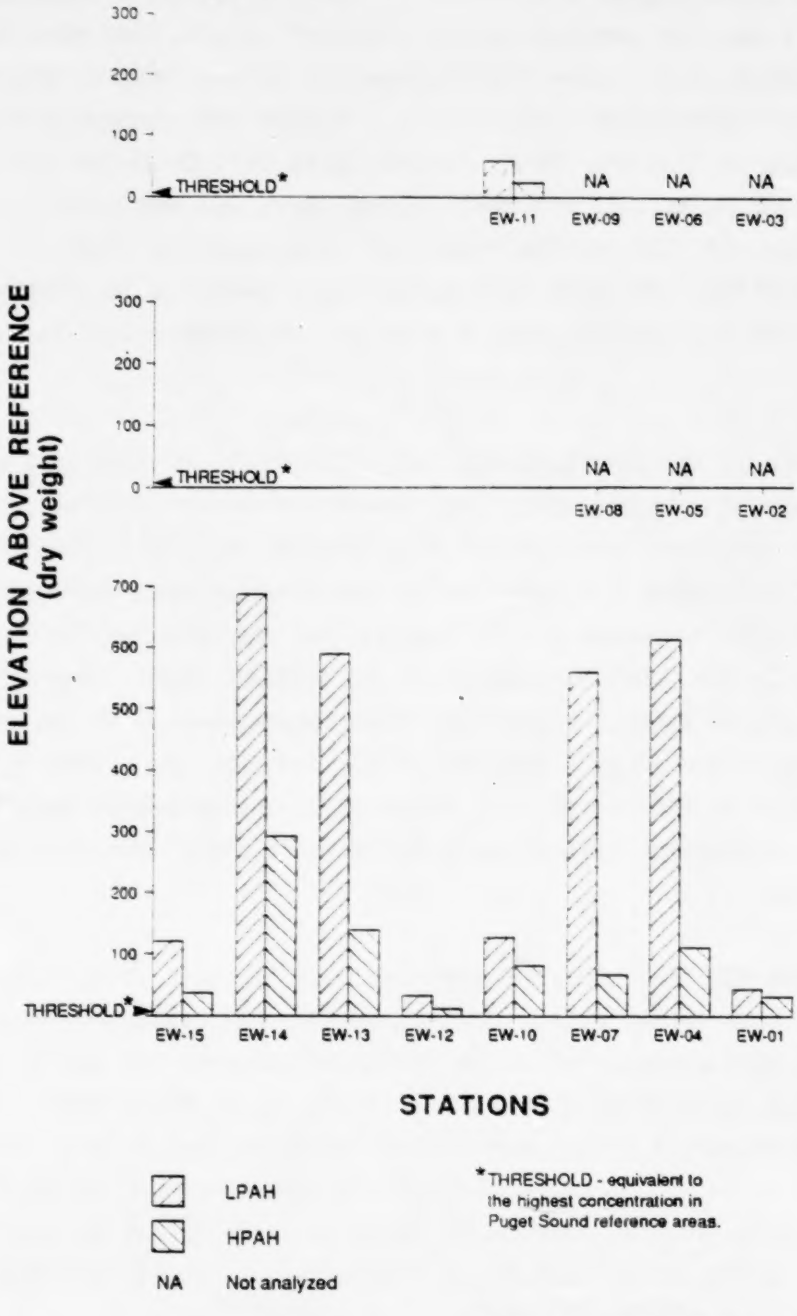
The PAH composition in East Waterway sediments was variable, but certain trends were apparent. LPAH concentrations throughout the East Waterway were comparable to or greater than HPAH concentrations (LPAH/HPAH ratios ranged from 0.7 to 4.2 with a mean of 1.8; n=9) (Figure 17). Such



* THRESHOLD - equivalent to the highest concentration in Puget Sound reference areas.

Reference: L41 µg/kg DW (LPAH) and L79 µg/kg DW (HPAH).

Figure 16. Mean EAR of LPAH and HPAH in sediments from all study areas.



Reference: L41 µg/kg DW (LPAH) and L79 µg/kg DW (HPAH).

Figure 17. EAR of LPAH and HPAH at individual stations in the East Waterway.

PAH compositions suggest a source other than combustion of organic material. Naphthalene was the predominant PAH compound in all East Waterway samples except Station EW-01, where fluoranthene and pyrene concentrations slightly exceeded the naphthalene concentration. Naphthalene concentrations exceeded EAR of 1,000 at Stations EW-07 (17,000 ug/kg DW), EW-13 (12,000 ug/kg DW), EW-04 (10,000 ug/kg DW), and EW-14 (7,000 ug/kg DW) and roughly equalled or exceeded EAR of 100 at the remaining East Waterway stations that were analyzed for PAH. Notably, PAH assemblages dominated by naphthalene were also observed in sediments near a pulp mill in Commencement Bay (Tetra Tech 1985a).

Outside of the East Waterway, PAH concentrations were most elevated in Areas OG and NG (Figure 16). PAH concentrations throughout Area OG were consistent among stations (LPAH = 750±150 ug/kg DW; HPAH = 640±180 ug/kg DW, n=7). All OG samples had very similar PAH compositions; naphthalene was the predominant PAH compound in all samples (as was observed in East Waterway sediments). The LPAH concentration at Station OG-01 (nearest the East Waterway) was at least 5 times lower than concentrations at the nearest East Waterway stations (e.g., Station EW-15) but was more than 4 times the concentration at intervening Station NG-01. Thus, based on the limited data available, a gradient indicating LPAH transport out of the East Waterway was not apparent.

In Area NG, PAH concentrations were most elevated at Stations NG-09 and NG-11, and to a lesser extent, Station NG-10. PAH contamination at Stations NG-09 and NG-11 was similar in terms of composition and concentration (3,500-4,100 ug/kg DW of LPAH and 8,700-9,000 ug/kg DW for HPAH). Concentrations were roughly 3 times lower at Station NG-10 than at Stations NG-09 and NG-11, and at least an order of magnitude lower at other NG stations. PAH compositions in Area NG were unlike those in Areas EW and OG, and had higher relative proportions of HPAH (e.g., fluoranthene, pyrene, and chrysene).

Polychlorinated Biphenyls--PCBs were seldom detected in this study (detection frequency = 7/54) and occurred at concentrations above 50 ug/kg DW (the maximum reference area detection limit) in only three samples. Sample EW-04 in the East Waterway had a highly elevated concentration of

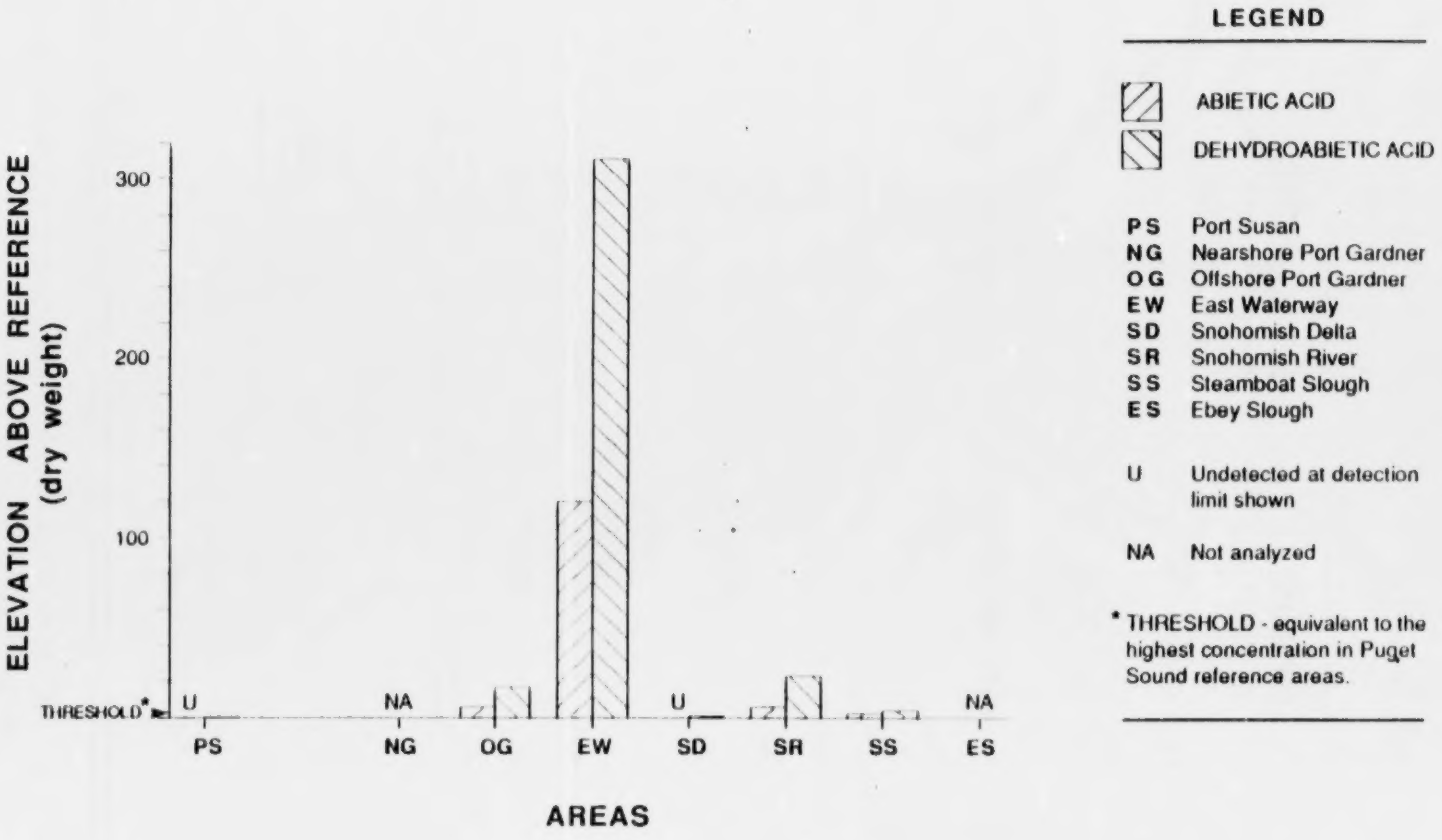
PCBs (9,600 ug/kg DW; EAR=1,600). PCBs were detected at a far lower concentration at adjacent Station EW-07 (87 ug/kg DW) and were undetected at all other EW stations at detection limits of 50 ug/kg DW or less. In Area NG, Sample NG-09 had a reported PCB concentration of 5,500 ug/kg DW (EAR=920). PCBs were undetected at detection limits of 50 ug/kg DW or less at nearby NG stations.

Resin Acids--The resin acids analyzed for this study include abietic acid, dehydroabietic acid (DHA), isopimaric acid, neoabietic acid, sandaracopimaric acid, 12- and 14-chlorodehydroabietic acid, and dichlorodehydroabietic acid (see Figure 15 for structures). Unchlorinated resin acids (or tricyclic diterpenoid acids) are among the predominant constituents of higher plant resins and supportive tissue, particularly in conifers (e.g., Simoneit 1986; Thomas 1970; Gough 1964). Dehydroabietic acid, typically the predominant resin acid found in the environment, is derived from abietic acid and is relatively stable as a result of its aromatic ring structure (e.g., Simoneit 1986). Although unchlorinated resin acids are naturally-occurring compounds, they are highly concentrated by pulping processes. The occurrence of resin acids, particularly DHA and abietic acid, has been well-documented in sulfite pulp effluents (e.g., Leuenberger et al. 1985; Leach and Thakore 1977) and in kraft effluents (e.g., Leach and Thakore 1973, 1977). Resin acids (e.g., DHA) have also been reported at elevated concentrations in sediments near pulp mill discharges (e.g., Brownlee et al. 1977). DHA is very persistent in sediments (a "half-life" of over 20 yr was estimated in Lake Superior sediments that were dated with ^{210}Pb) (Brownlee et al. 1977).

Chlorine bleaching processes used by the pulp industry have been demonstrated to result in the formation of chlorinated resin acids (i.e., chlorinated DHA derivatives) in bleached sulfite and kraft effluents (Leuenberger et al. 1985; Claeys et al. 1980; Leach and Thakore 1975, 1977). Chlorinated derivatives of DHA are by far the predominant chlorinated resin acids reported in bleached pulp effluents, presumably because the stability of DHA relative to other resin acids enables it to survive the strong oxidizing conditions of chlorine bleaching. Chlorinated resin acids, because of their unique origin, are powerful geochemical tracers of pulp mills that use chlorine bleaching processes. Many other chlorinated compounds can be produced by pulp mills, including many acid and neutral semivolatile organic compounds (e.g., Carlberg et al. 1986; Leuenberger et al. 1985; Kringstad and Lindstrom 1984; Claeys et al. 1980) as well as high-relative-molecular-mass organic material ($M_r>1,000$) of poorly defined structure. This latter material can constitute the majority of organically bound chlorine in spent chlorination and alkali extraction liquors from the bleaching of softwood kraft pulp (e.g., Kringstad and Lindstrom 1984), but is not amenable to typical GC/MS analysis.

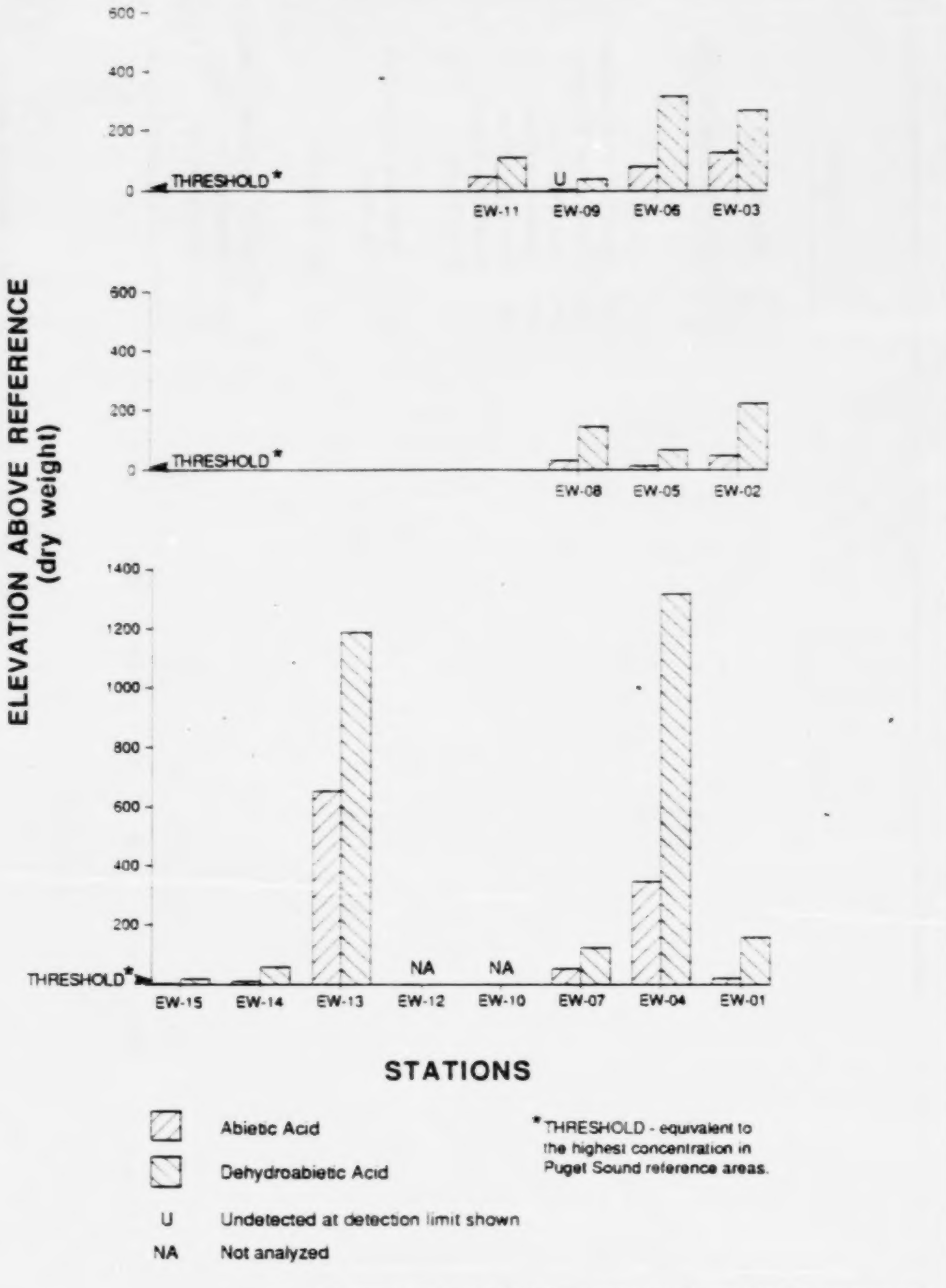
Concentrations of all resin acids were most elevated in the East Waterway. Mean EAR values for DHA and abietic acid, which were the most concentrated and among the most frequently detected resin acids, were 310 and 120, respectively, in the East Waterway (Figure 18). These mean EAR were over 13 times higher than those of other study areas (note that samples in Areas NG and ES were not analyzed for resin acids). Similarly, mean EAR values of other resin acids in the East Waterway were typically at least 8 times higher than in other study areas. Outside of the East Waterway, Areas SR and OG typically had the next highest concentrations of resin acids (e.g., Figure 18).

Distributions of DHA and abietic acid in the East Waterway are presented in Figure 19. DHA and abietic acid were similarly distributed; however, DHA maximized at Station EW-04 (83,000 ug/kg DW; EAR=1,300), whereas abietic acid maximized at Station EW-13 (98,000 ug/kg DW; EAR=650). As was observed for virtually all chemicals in the study, the maximum concentrations in the East Waterway occurred along the east shore. Along this shore, a bimodal distribution was apparent, with maxima at Stations EW-04 and EW-13 (Figure 19). The interpretation of this bimodal distribution was impeded by the lack of data at Stations EW-10 and EW-12 (resin acids were not analyzed at these stations) and by variations in sediment TOC content along the east shore (see Figure 10). Nonetheless, TOC-normalized DHA and abietic acid concentrations also appeared to follow a bimodal distribution. Although concentrations of DHA and abietic acid at Stations EW-04 and EW-13 were predominant in the East Waterway, concentrations were highly elevated throughout the East Waterway; for DHA, EAR values of >100 were reported at 9 of the 13 stations in the East Waterway (Figure 19).



Reference: U150 µg/kg DW (abietic acid) and L63 µg/kg DW (dehydroabietic acid)

Figure 18. Mean EAR of abietic acid and dehydroabietic acid at individual stations in the East Waterway.



Reference: U150 µg/kg DW (abietic acid) and L63 µg/kg DW (dehydroabietic acid)

Figure 19. EAR of abietic acid and dehydroabietic acid at individual stations in the East Waterway.

Distributions of other unchlorinated resin acids in the East Waterway were similar to those of DHA and abietic acid, but several discrepancies are noteworthy. Sandaracopimaric acid occurred at high concentrations at Stations EW-04 and EW-13, but was most concentrated at Station EW-01 (14,000 ug/kg DW; EAR=95) (Figure 20). Strong gradients were apparent for sandaracopimaric acid along the east shore of the East Waterway (Figure 20). However, it should be noted that sandaracopimaric acid concentrations in duplicate analyses for Station EW-07 were not in close agreement (see **Sediment Chemistry, Quality Assurance/Quality Control Results** in **Methods** section). Isopimaric acid covaried with abietic acid in the East Waterway ($r=0.92$, $n=18$, $P<0.05$; study-wide), with a maximum concentration at Station EW-13 (11,000 ug/kg DW; EAR=73). Neoabietic acid also maximized at Station EW-13 (14,000 ug/kg DW; EAR=93), although this concentration was over 18 times that of any other station in the East Waterway. In addition, the detection frequency of neoabietic acid was low in the East Waterway relative to those of other unchlorinated resin acids (46 percent for neoabietic acid as compared to over 90 percent for other unchlorinated resin acids).

Like DHA, 12- and 14-chlorodehydroabietic acids had maximum concentrations at Station EW-04 (12-chlorodehydroabietic acid = 11,000 ug/kg DW, EAR=73) (Figure 21). However, in contrast to the bimodal distribution observed for DHA and abietic acid in the East Waterway, monochlorodehydroabietic acids had maxima toward the head of the waterway without a comparably high concentration at Station EW-13. Dichlorodehydroabietic acid (not shown in Figure 21) also maximized at Station EW-04 (710 ug/kg DW; EAR=4.7) but had comparable concentrations at Stations EW-07 and EW-13 (EAR=4-5). Dichlorodehydroabietic acid was detected at lower concentrations at two other stations in the East Waterway (Stations EW-03 and EW-05) and was not detected in any other study areas.

Resin acids were detected in Area OG, but at far lower concentrations than were typically observed in the East Waterway. Concentrations of DHA and abietic acid were the most elevated among the resin acids detected in Area OG. Maximum concentrations of these resin acids occurred at Station OG-03 (DHA=1,500 ug/kg DW; EAR=24; abietic acid = 1,700 ug/kg DW; EAR=11), although concentrations were typically very consistent for all OG samples

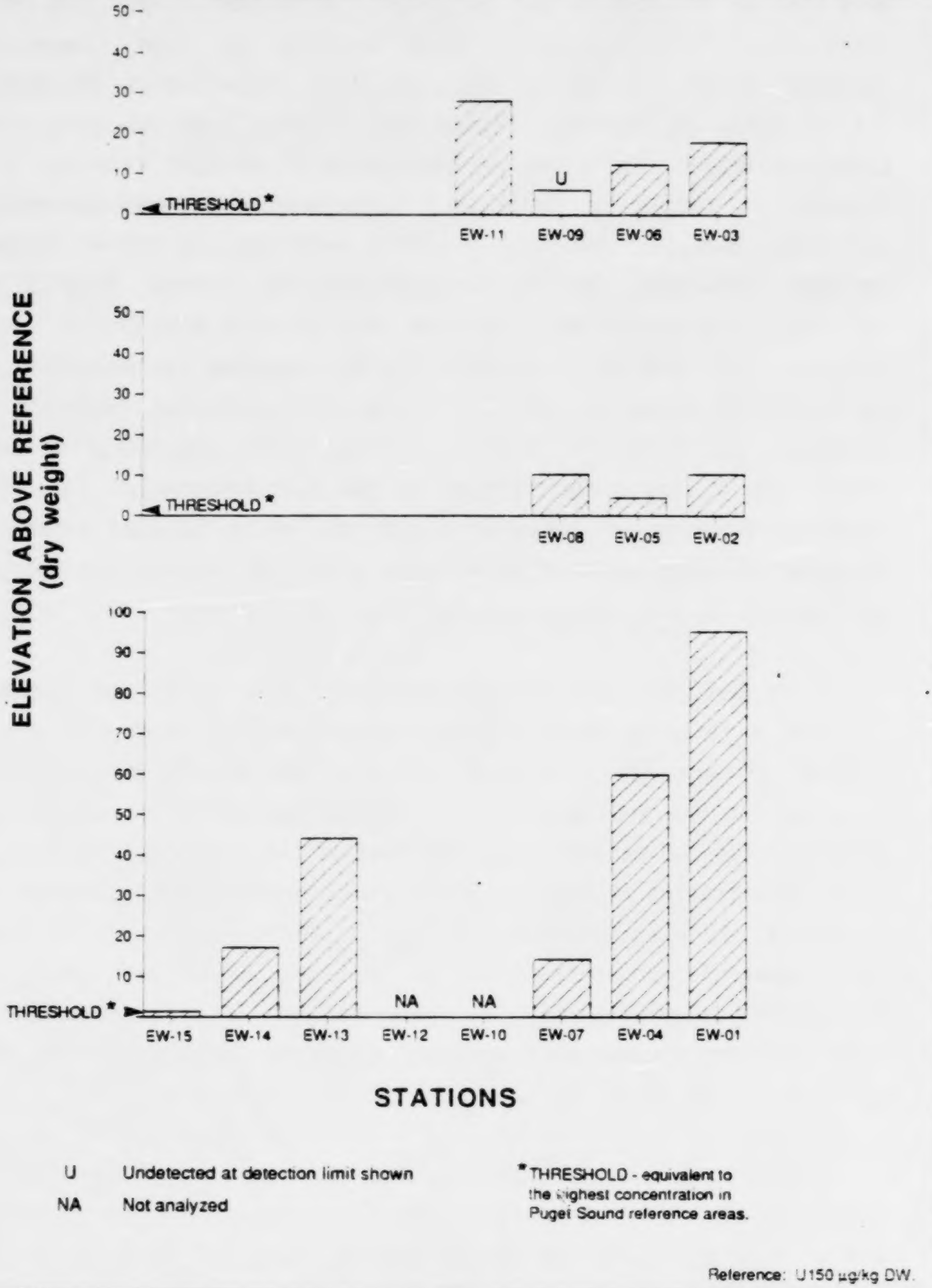
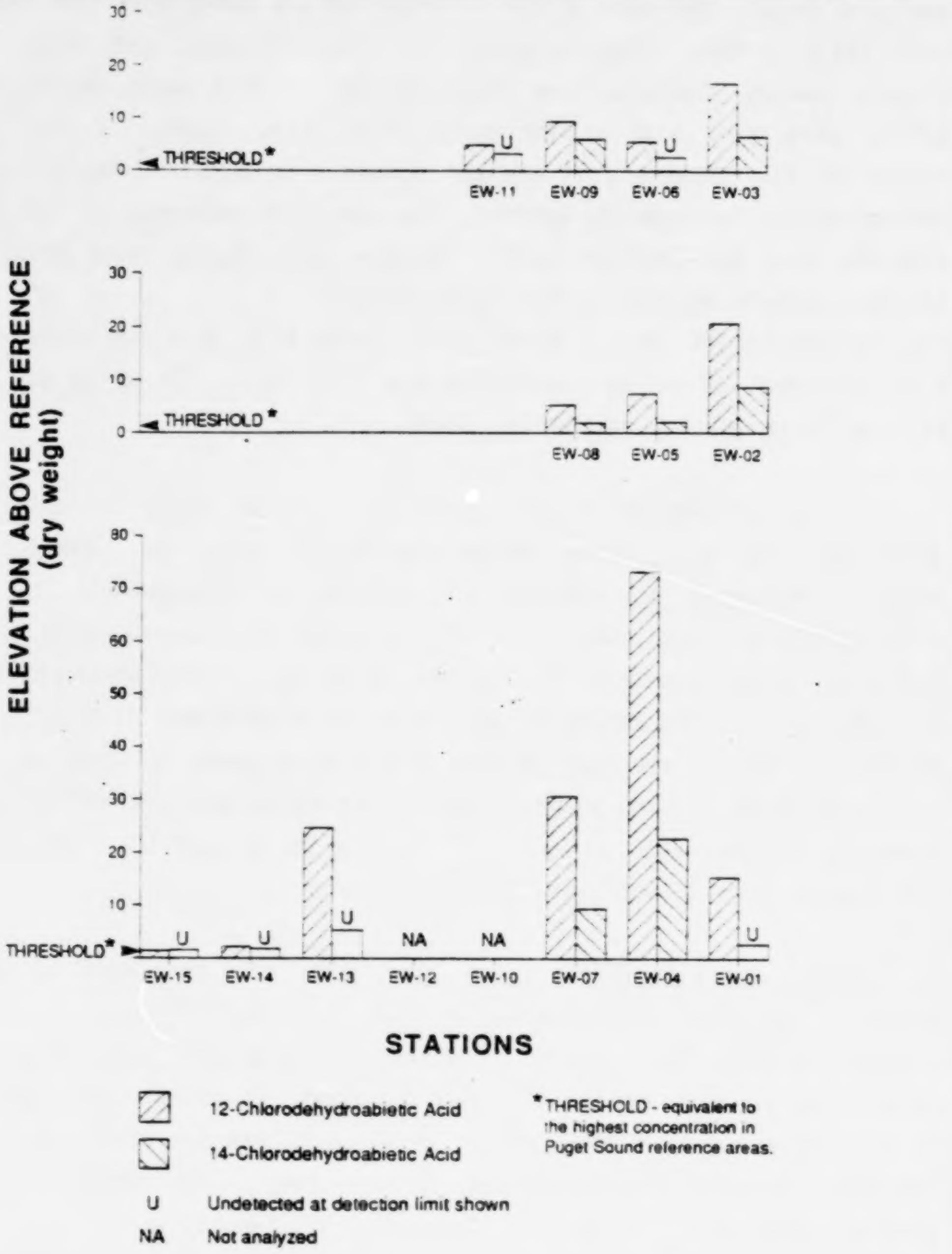


Figure 20. EAR of sandaracopimaric acid at individual stations in the East Waterway.



Reference: U150 µg/kg DW (12- and 14-chlorodehydroabietic acid).

Figure 21. EAR of 12- and 14-chlorodehydroabietic acids at individual stations in the East Waterway.

analyzed (e.g., agreement within a factor of 2-3 among most stations and for most resin acids). Concentrations at Stations OG-02 and EW-15, the most closely spaced stations from Areas OG and EW that were tested for resin acids, were very similar for most resin acids (typically well within a factor of 2). However, it was not possible to discern whether resin acid contamination in Area OG derived from the East Waterway or had dispersed from the area near Station OG-03. Notably, chlorinated resin acids (12- and 14-chlorodehydroabietic acids) were detected in Area OG but at relatively low concentrations (e.g., 12-chlorodehydroabietic acid was detected at all 5 OG stations tested at concentrations from 78 to 270 ug/kg DW, with the maximum concentration at Station OG-06).

In the Snohomish River (Area SR), resin acid contamination was most prevalent at Station SR-05 (DHA=3,500 ug/kg DW, EAR=56; abietic acid = 2,300 ug/kg DW, EAR=15). Concentrations at adjacent Station SR-04 were roughly 5 times lower. The only detected chlorinated resin acid in the Snohomish River occurred at Station SR-04 (12-chlorodehydroabietic acid, 61 ug/kg DW). In Steamboat Slough, resin acids were most frequently detected at Station SS 02, although several resin acids were detected at less than 250 ug/kg DW at Station SS-03. The highest resin acid concentration in this area was for DHA (730 ug/kg DW at Station SS-02, EAR=12). No chlorinated resin acids were detected in Steamboat Slough.

Phenol and Alkyl-Substituted Phenols--Of the compounds in this group (phenol, 2- and 4-methylphenol, and 2,4-dimethylphenol), phenol and 4-methylphenol were both frequently detected, but 4-methylphenol concentrations were by far the most elevated. 4-Methylphenol was detected in over 90 percent of the samples in which it was analyzed and occurred at the most elevated concentrations of any chemical measured in this study (maximum EAR=7,500). Roughly 30 percent of 4-methylphenol concentrations exceeded an EAR of 100 and roughly 9 percent exceeded an EAR of 1,000 (all of the latter group were from the East Waterway). Of all the study areas, the highest mean 4-methylphenol concentration was observed in the East Waterway (mean = 25,000 ug/kg DW; EAR=1,900) (Figure 22). However, the mean EAR in Area NG exceeded 100 (EAR=120) and the mean EAR in Area OG was 71.

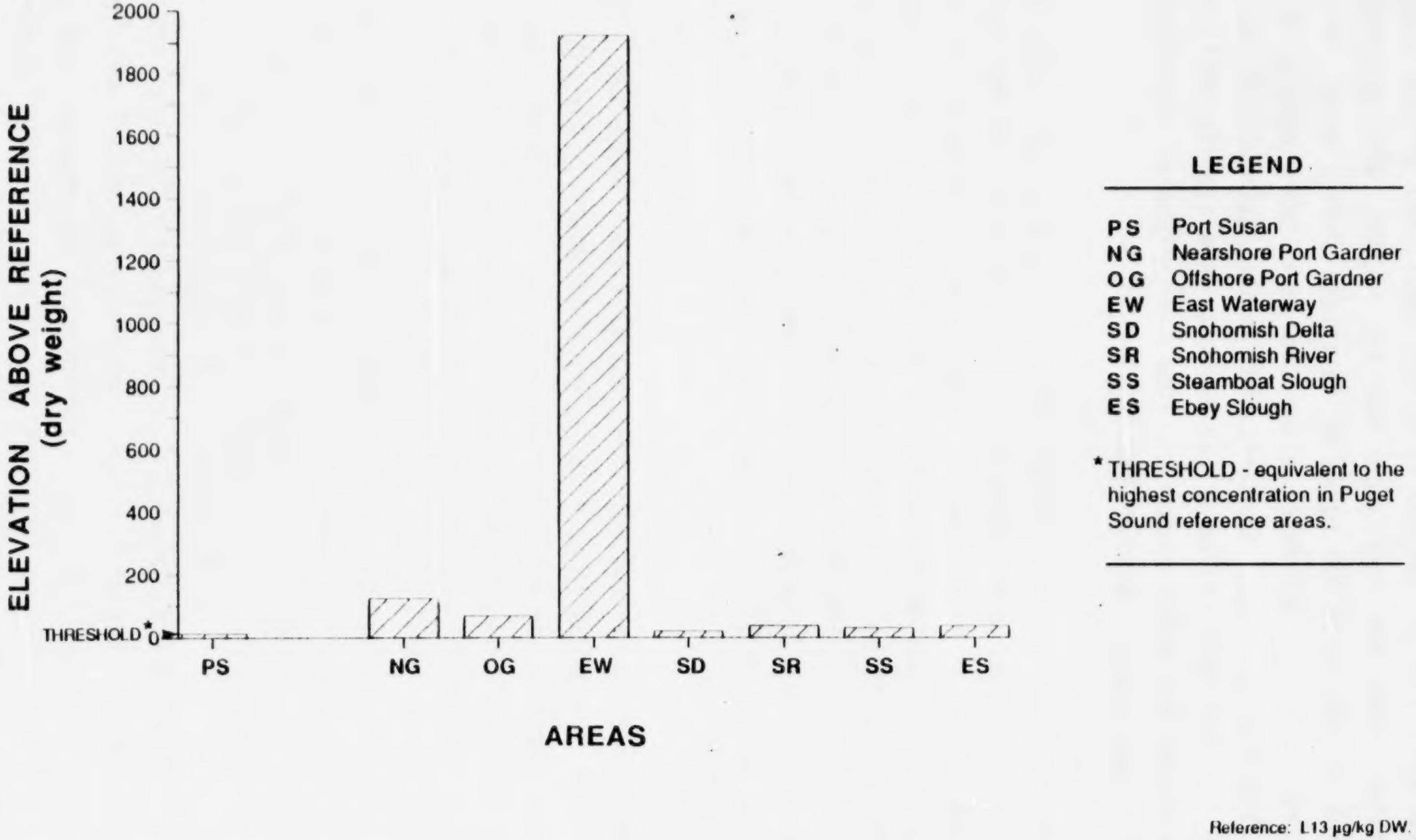


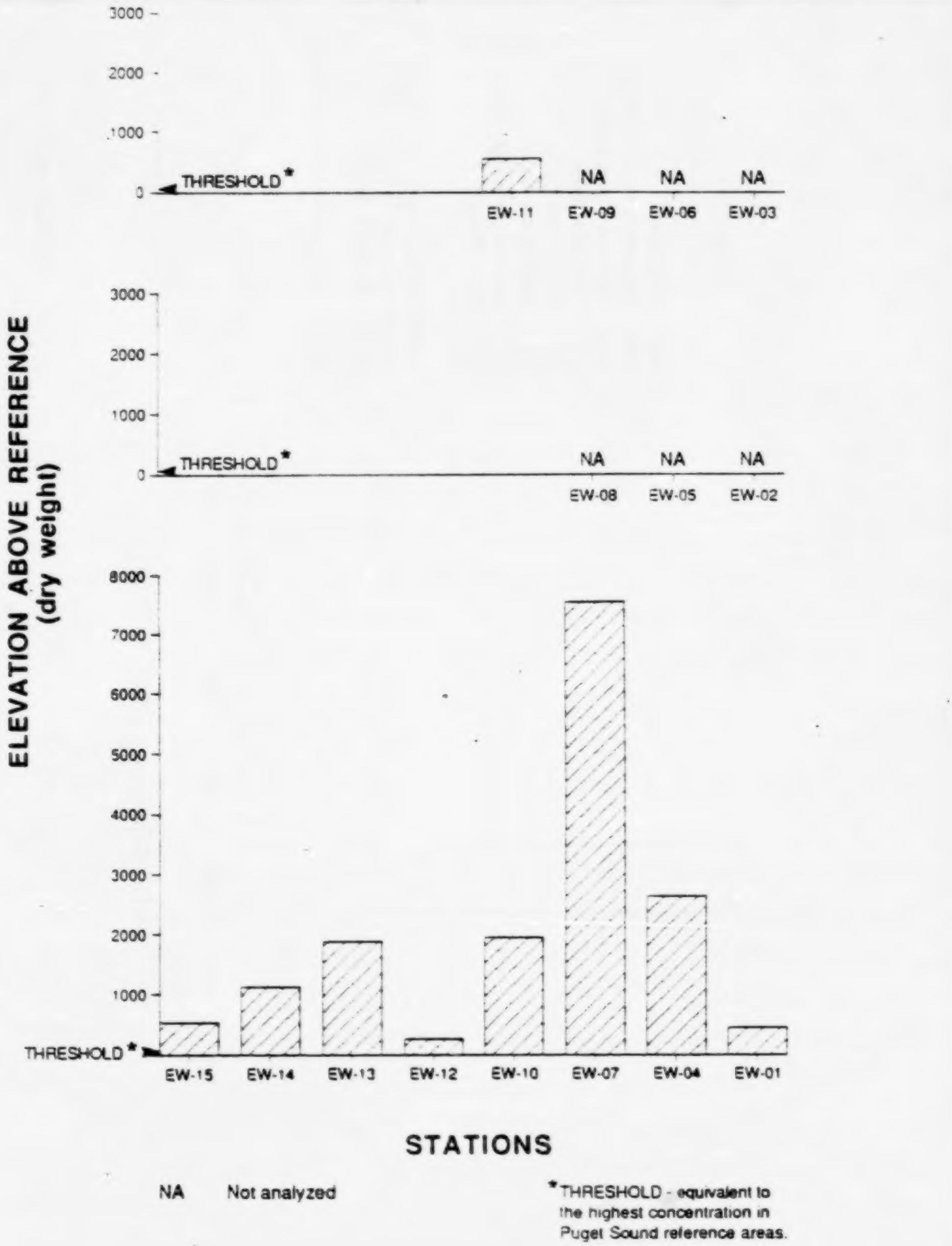
Figure 22. Mean EAR of 4-methylphenol in sediments from all study areas.

Within the East Waterway, the highest 4-methylphenol concentration was observed at Station EW-07 (98,000 ug/kg DW; EAR=7,500) (Figure 23). Four other stations along the east shore had EAR >1,000, with concentrations ranging from 15,000 to 35,000 ug/kg DW (Stations EW-04, EW-10, EW-13, and EW-14). Concentrations decreased along the east shore moving in either direction from Station EW-07. Contamination in the East Waterway toward the west shore was not well characterized because only Station EW-11 in that area was analyzed for A/B/N compounds. The 4-methylphenol concentration at Station EW-11 was highly elevated (EAR=550).

Area NG also had elevated 4-methylphenol concentrations. However, the highest concentrations were observed at Station NG-05 (9,700 ug/kg DW; EAR=730) and nearby stations, not at stations near the mouth of the East Waterway (e.g., Stations NG-01 and NG-12; U20 to 500 ug/kg DW). Hence, 4-methylphenol contamination in Area NG did not appear to derive from the East Waterway. EAR values >100 were observed at Stations NG-04, NG-09, NG-10, NG-11, and NG-14 (all between 1,600 and 2,400 ug/kg DW). Concentrations were somewhat patchy in this area, but did not exceed 1,000 ug/kg DW at any other NG stations.

4-Methylphenol concentrations were generally consistent among stations in Area OG (EAR from 68 to 97 at Stations OG-01 to OG-05). Distributions of 4-methylphenol between the East Waterway mouth and OG stations nearest the mouth did not suggest that 4-methylphenol contamination in Area OG derived from the more contaminated East Waterway. The 4-methylphenol concentration at Station OG-01 (nearest the East Waterway) was at least 5 times lower than concentrations at the nearest East Waterway stations (e.g., Station EW-15) but was more than double the concentration at intervening Station NG-01. In other areas, high 4-methylphenol concentrations (EAR >100) occurred at Station SR-05 (2,000 ug/kg DW) and Station ES-03 (1,400 ug/kg DW).

Phenol, like 4-methylphenol, was detected frequently (detection frequency >90 percent) but at far lower concentrations than 4-methylphenol. The mean EAR for phenol in the East Waterway (40) was greater than that of any other study area (Figure 24); Areas NG, OG, and ES all had mean EARs between 11 and 17. Laboratory contamination of phenol was observed for two



Reference: L13 µg/kg DW.

Figure 23. EAR of 4-methylphenol at individual stations in the East Waterway.

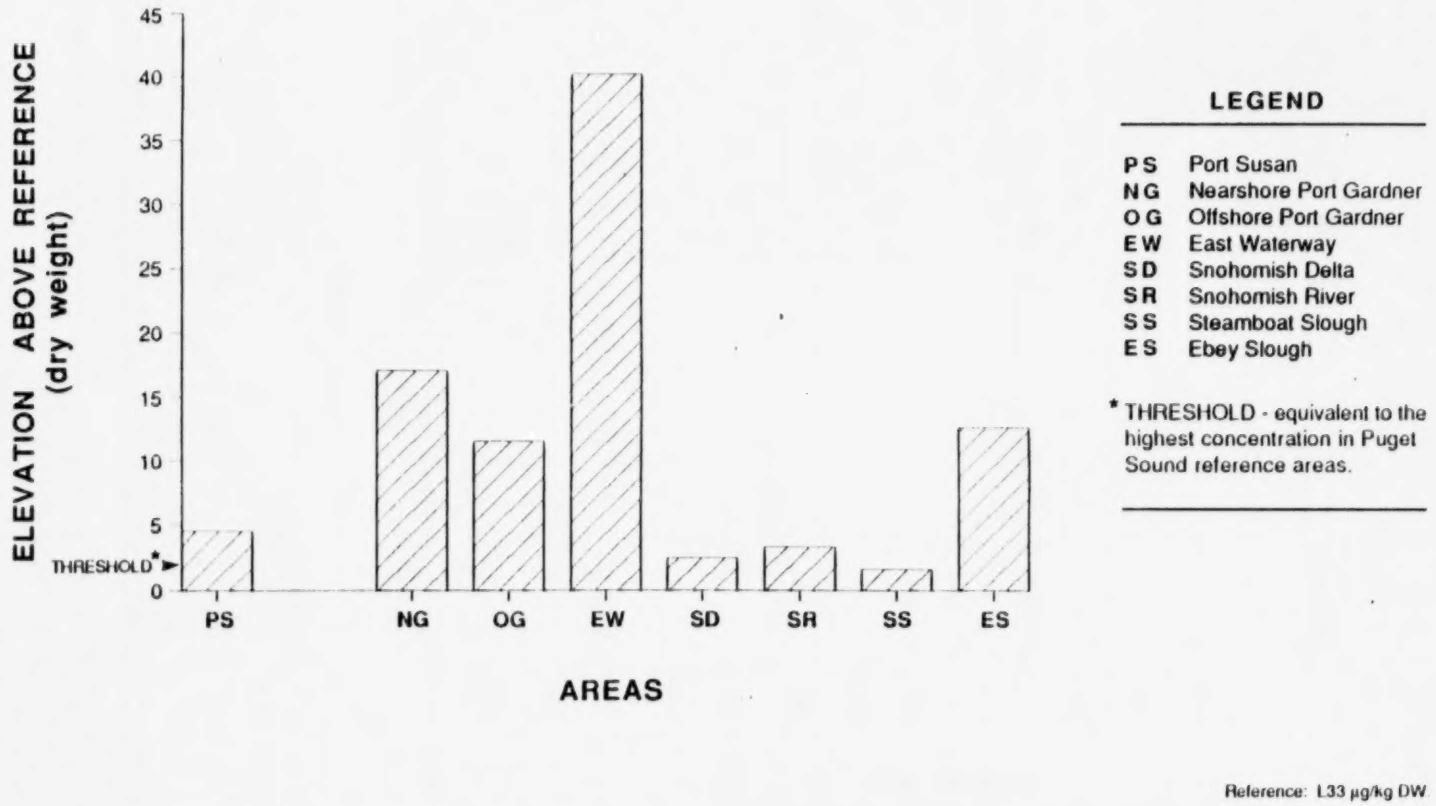


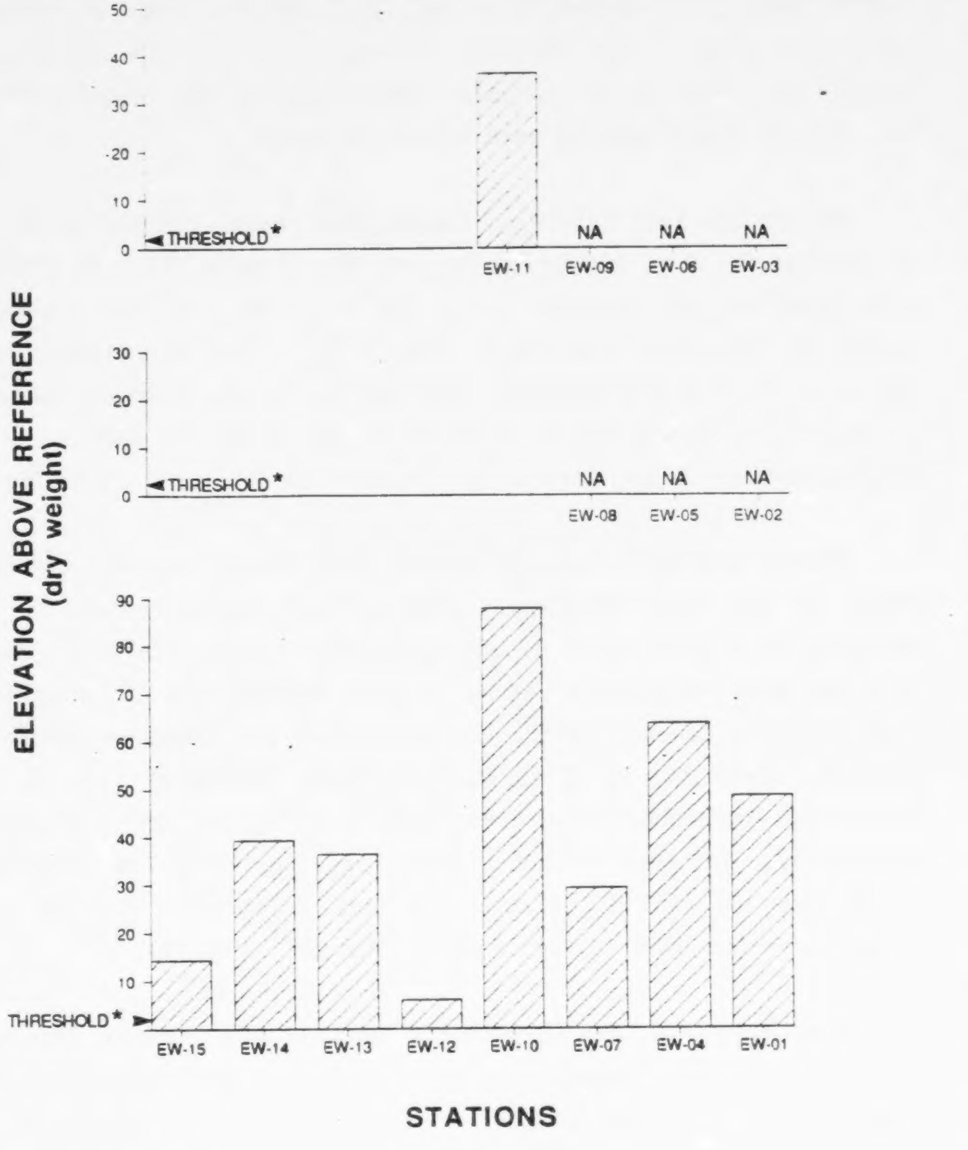
Figure 24. Mean EAR of phenol in sediments from all study areas.

blanks analyzed during this study (see **Chemistry, Quality Assurance/Quality Control Results** in **Methods** section), although the level of contamination was relatively minor. For the samples associated with the contaminated laboratory blank, laboratory contamination accounted for roughly 20 to 30 ug/kg DW. All of these samples were blank-corrected.

Within the East Waterway, the maximum phenol concentration was observed at Station EW-10 (2,900 ug/kg DW; EAR=88) (Figure 25). No clear concentration gradient was apparent along the east shore of the waterway on a dry weight or TOC-normalized basis (Figure 25). The only sample analyzed near the west shore of the waterway, Station EW-11, had a concentration comparable to most stations on the east shore (1,200 ug/kg DW; EAR=36). Only one EW sample required blank correction (Station EW-01; 1,600 ug/kg DW).

Phenol concentrations at certain stations in Area NG were comparable to those in the East Waterway. The maximum concentration in Area NG was observed at Station NG-09 (2,100 ug/kg DW, EAR=64). Overall, phenol concentrations were relatively patchy (Figure 26) and did not suggest dispersion from a single source. Blank correction was performed on concentrations for Stations NG-06 and NG-12 to NG-15. Phenol concentrations in Area OG were consistent throughout the area (380±73 ug/kg DW; n=7, all values blank-corrected). In Ebey Slough, phenol was detected at Station ES-03 at 1,200 ug/kg DW (EAR=36, blank-corrected). The other two ES stations were blank-corrected down to detection limits (25 ug/kg DW).

2-Methylphenol and 2,4-dimethylphenol were seldom detected in this study (the former compound was detected three times and the latter, twice) (see Table 17). Both phenols occurred at Stations EW-04 and EW-07, with maximum concentrations at the former station. 2-Methylphenol was reported at 1,200 ug/kg DW (EAR=170) at Station EW-04 and at 330 ug/kg DW (EAR=47) at adjacent Station EW-07. Detection limits were somewhat high (200 ug/kg DW) at nearby Stations EW-10 and EW-12, but did not greatly interfere with data interpretation. 2,4-Dimethylphenol was detected at 520 ug/kg DW (EAR=76) at Station EW-04 and occurred at 100 ug/kg DW (EAR=15) at Station EW-07. 2,4-Dimethylphenol was undetected throughout the rest of the East Waterway at detection limits of 20-50 ug/kg DW.



NA Not analyzed

*THRESHOLD - equivalent to the highest concentration in Puget Sound reference areas.

Reference: L33 µg/kg DW.

Figure 25. EAR of phenol at individual stations in the East Waterway.

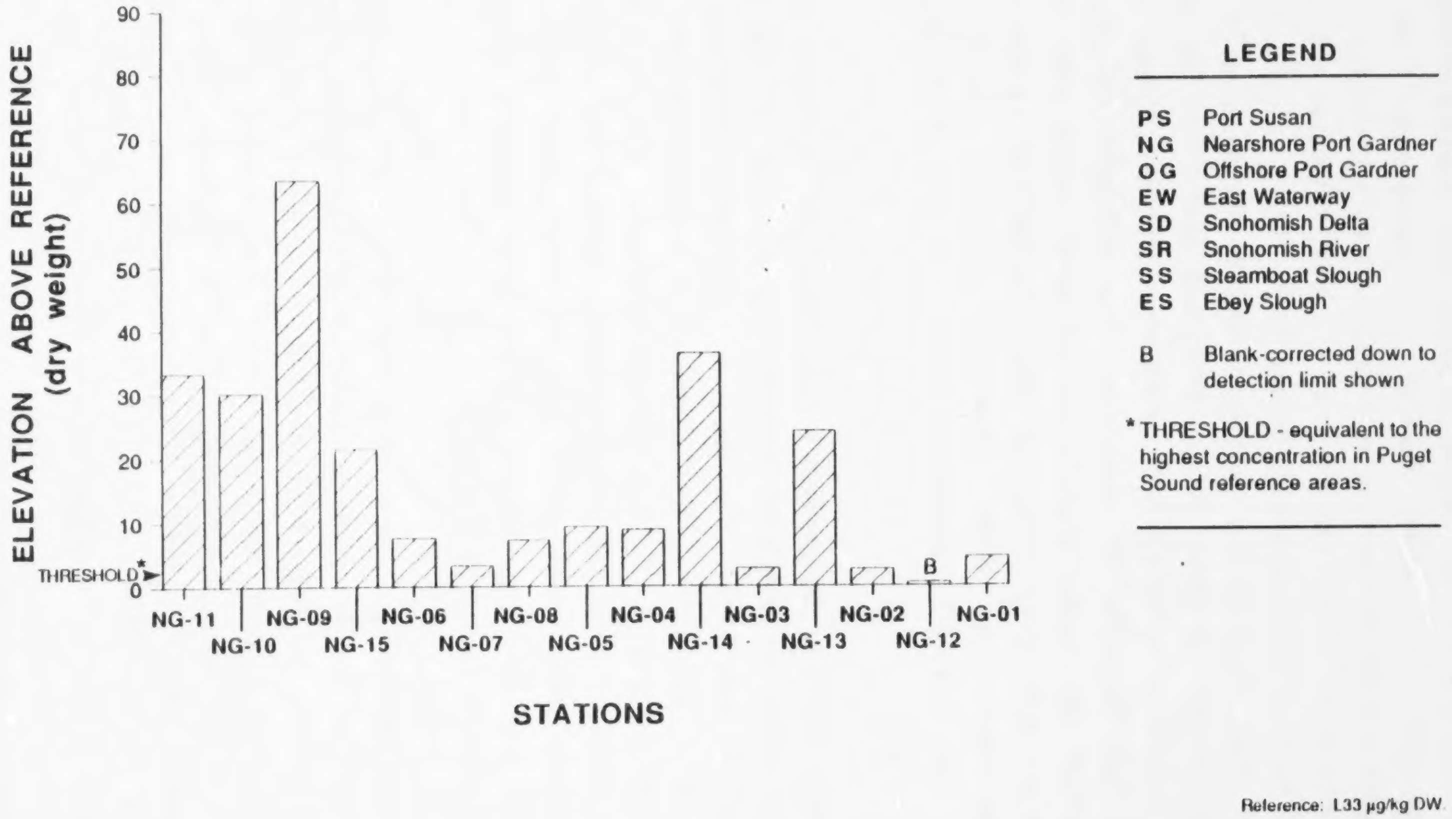


Figure 26. EAR of phenol at individual stations in Area NG.

Chlorinated Phenols and Guaiacols--Certain chlorinated phenols have been commercially produced for various purposes (e.g., pentachlorophenol, or PCP, has been used as a biocide); however, chlorinated phenols and chlorinated guaiacols are well-documented by-products of pulp bleaching processes (e.g., Carlberg et al. 1986; Leuenberger et al. 1985, Kringstad and Lindstrom 1984, Claeys et al. 1980, Leach and Thakore 1975, 1977). Lignin, a primary component of wood, is a natural polymer formed by the mixture of various 4-hydroxyarylpropenyl alcohols (e.g., Kringstad and Lindstrom 1984 and references therein). The chlorine bleaching process, through various substitution and dealkylation mechanisms, can depolymerize lignin and generate various chlorinated phenols and guaiacols, among other phenolic compounds (e.g., catechols) (Kringstad and Lindstrom 1984, Leuenberger et al. 1985, and Claeys et al. 1980). Chlorinated guaiacols, like chlorinated resin acids, are excellent geochemical tracers of pulp mills because of their unique origin.

Chlorinated phenols and guaiacols (see structures in Figure 15) were detected most often in the East Waterway and occurred at the highest concentrations in that area. For the nine chlorinated phenols/guaiacols analyzed in this study (i.e., 2-chlorophenol, 2,4-dichlorophenol, 2,4,5- and 2,4,6-trichlorophenol, 2,3,4,6-tetrachlorophenol, PCP, 3,4,5- and 4,5,6-trichloroguaiacol, and tetrachloroguaiacol), maximum EAR values within the East Waterway ranged from 12 to 47 (n=9) with a mean of 30 (n=9); outside of the East Waterway, maximum EAR for these compounds ranged from 0.5 to 14 (n=9), with a mean of 3.9 (n=9).

Chlorinated phenols/guaiacols tended to have similar distribution patterns within the East Waterway, but several important distinctions were apparent. Di-, tri-, and tetrachlorophenol distributions corresponded well in the East Waterway (and in the overall study, $r>0.8$ for all correlations between 2,4-dichlorophenol, 2,4,5- and 2,4,6-trichlorophenol, and 2,3,4,6-tetrachlorophenol). Distributions of 2,4-dichlorophenol and 2,4,6-trichlorophenol (Figure 27) are representative of this group of compounds. As is apparent in Figure 27, correlations between 2,4-dichlorophenol and 2,4,6-trichlorophenol were particularly strong ($r>0.99$, n=19, $P<0.05$). For di- through tetrachlorophenols, maximum concentrations were observed at the head

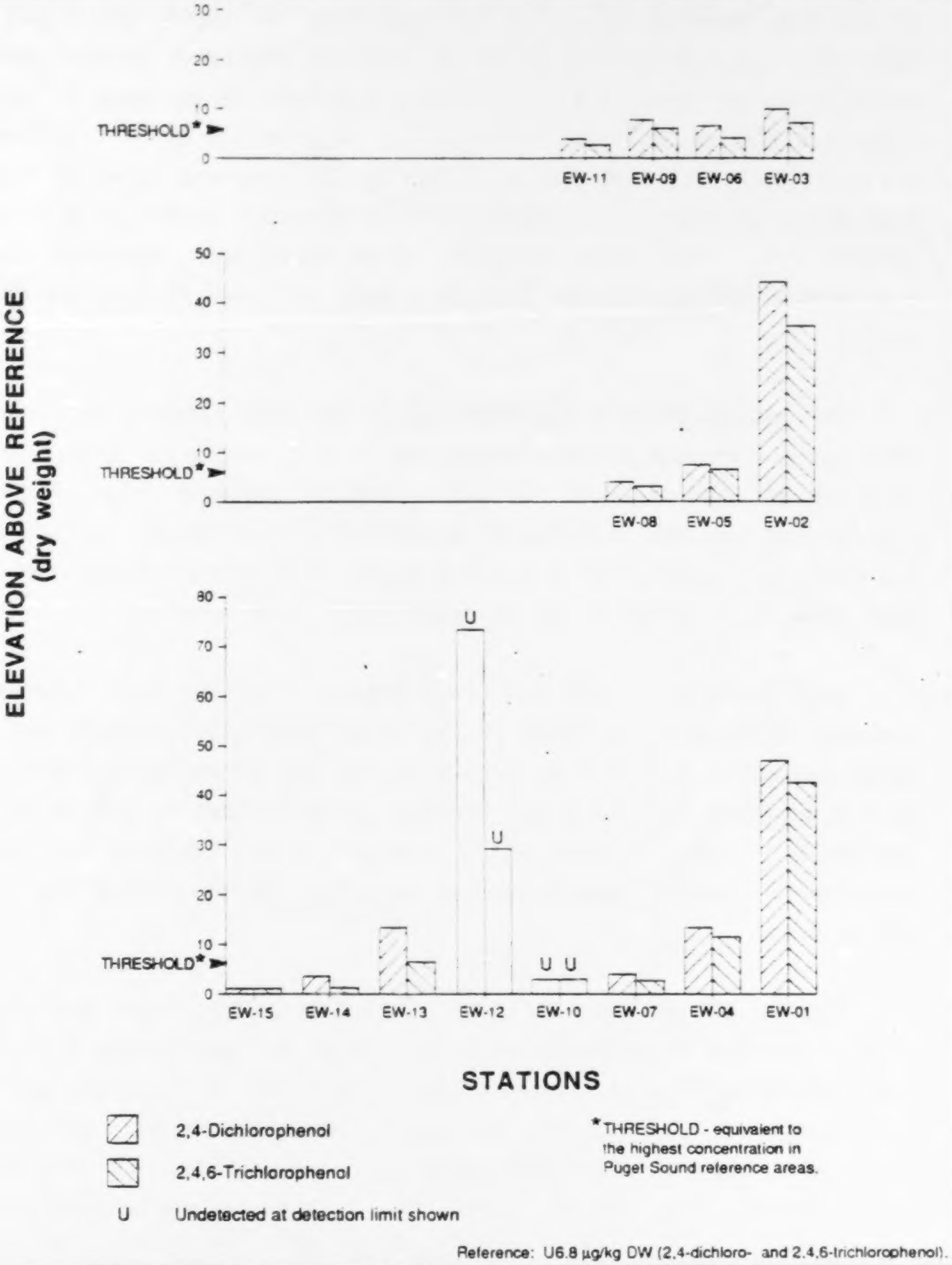


Figure 27. EAR of 2,4-dichlorophenol and 2,4,6-trichlorophenol at individual stations in the East Waterway.

of the East Waterway (i.e., at Stations EW-01 and EW-02; see Figure 27 and Table 17). Concentrations of these compounds decreased sharply toward the mouth of the waterway (e.g., Figure 27), although the decrease in concentration from Station EW-01 to EW-04 was not as great for 2,4,5-trichlorophenol and 2,3,4,6-tetrachlorophenol as it was for the compounds shown in Figure 27. High detection limits were reported for chlorinated phenols at Station EW-12 (Figure 27). Full-scan analyses, which were less sensitive than the dedicated chlorinated phenol analyses, were performed at Stations EW-12 and EW-10.

Chlorinated guaiacol distributions in the East Waterway were similar to those of di- through tetrachlorophenols in that strong concentration maxima occurred at Station EW-01 for all guaiacols analyzed (e.g., Figure 28). However, unlike the chlorinated phenols discussed above, all chlorinated guaiacols were undetected at Station EW-02. 3,4,5-Trichloroguaiacol was the most commonly detected of the chloroguaiacols (see Table 17).

Distributions of PCP and 2-chlorophenol in the East Waterway were somewhat different than those of the other chlorinated phenols and chlorinated guaiacols; both PCP and 2-chlorophenol had strong concentration maxima at Station EW-04 (see Table 17), whereas concentrations at Station EW-01 were considerably lower (Figure 29). However, as was observed for the other chlorinated phenols, concentrations decreased sharply toward the mouth of the waterway.

Outside of the East Waterway, chlorinated phenols and guaiacols were seldom detected at concentrations exceeding the maximum detection limits reported in Puget Sound reference areas (see Table 18) (in fact, most detected values were <10 ug/kg DW). Among the chlorinated phenols, 2-chlorophenol occurred at the highest concentration outside of the East Waterway (36 ug/kg DW at Station SD-02; EAR=10). Dichloro-, trichloro-, and pentachlorophenols were detected at most OG stations, but typically at $\leq$5 ug/kg DW. Similar chlorinated phenol results were observed at Station SS-03 in Steamboat Slough. Chlorinated guaiacols were detected a total of seven times outside of the East Waterway (at Stations OG-07, SD-02, SS-02, SS-03, SS-04, and SS-06). The highest concentration occurred at Station SS-04 [43 ug/kg DW for

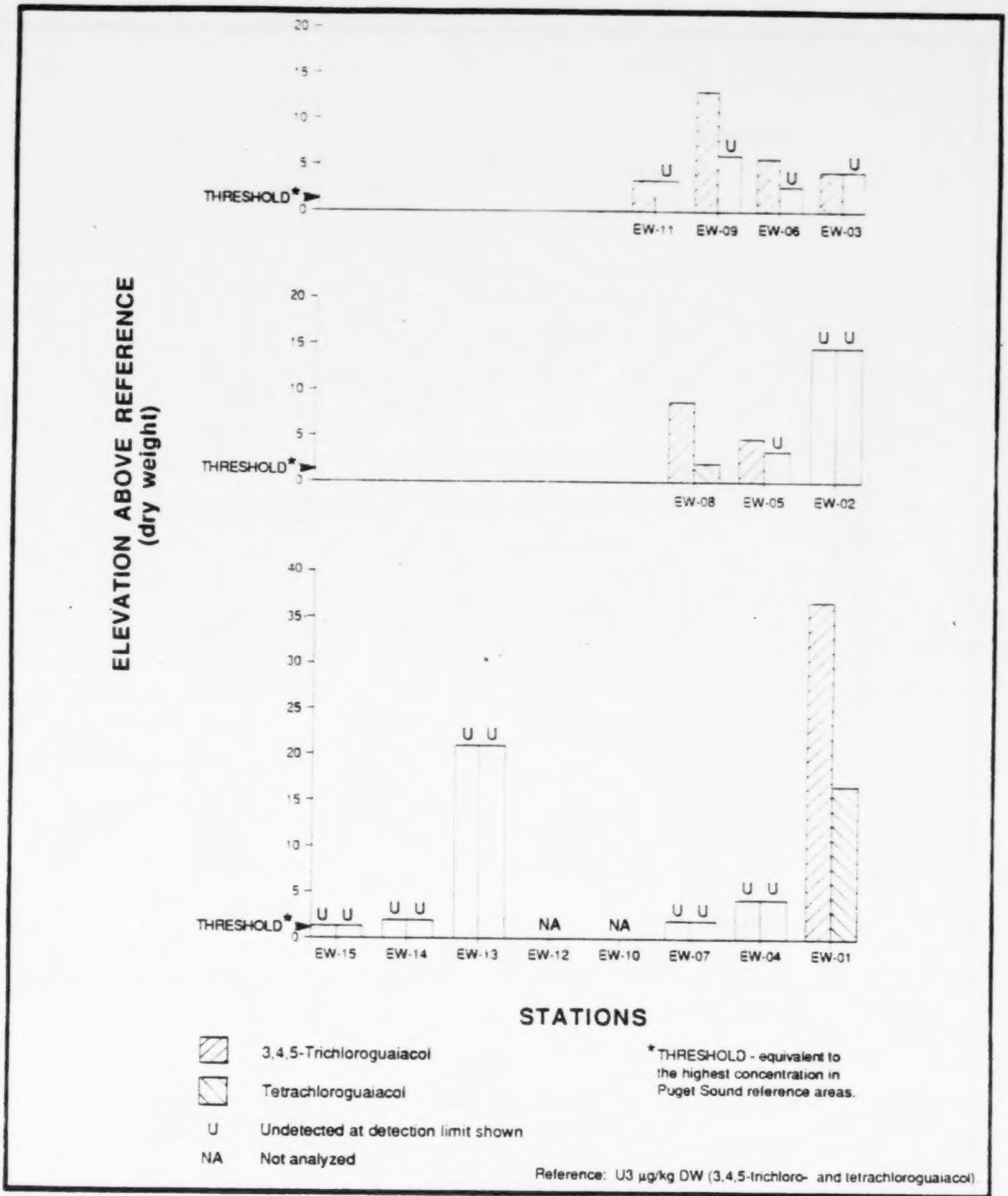


Figure 28. EAR of 3,4,5-trichloroguaiacol and tetrachloroguaiacol at individual stations in the East Waterway.

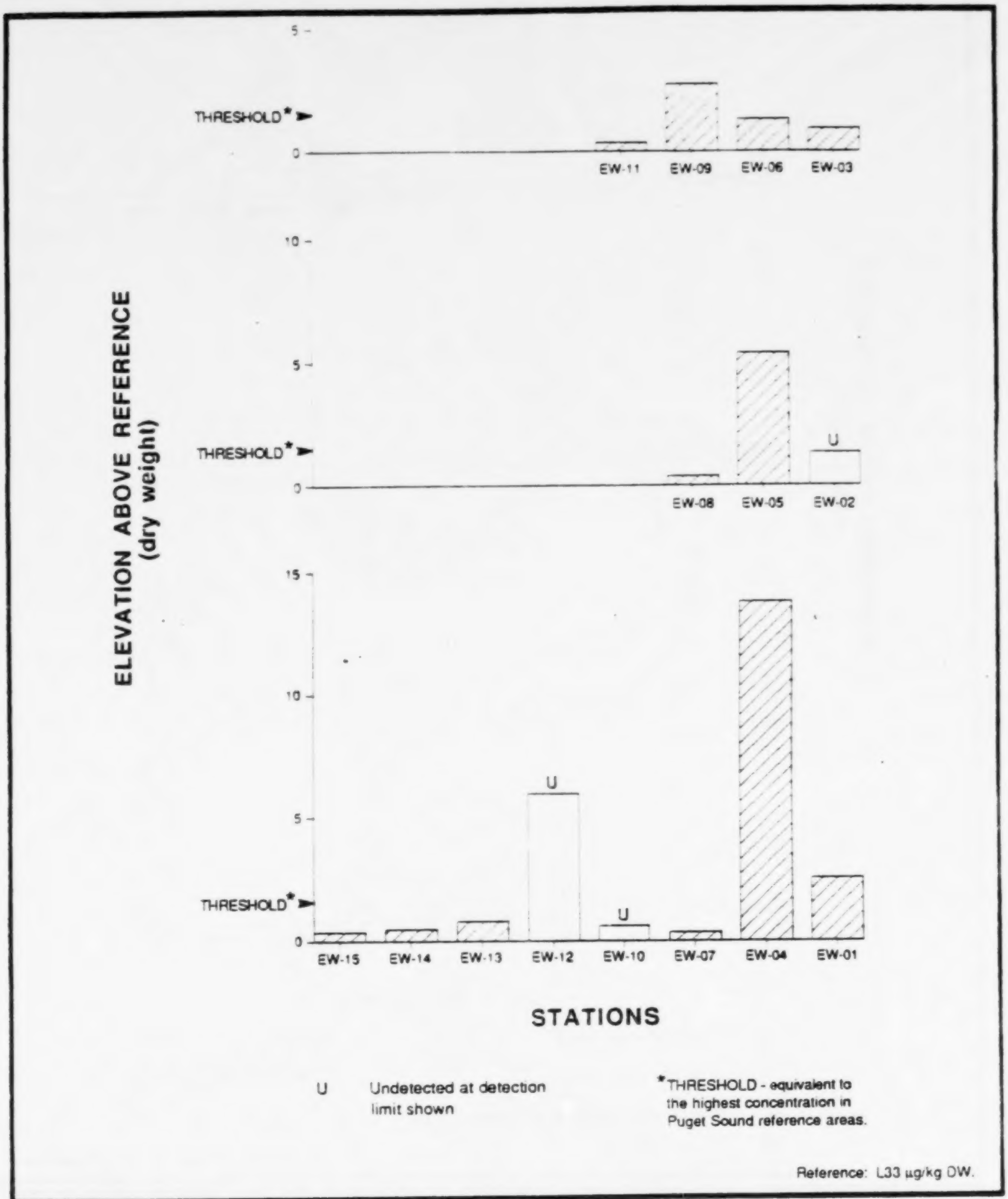


Figure 29. EAR of pentachlorophenol at individual stations in the East Waterway.

4,5,6-trichloroguaiacol (EAR=14)]. All other chlorinated guaiacol concentrations outside of the East Waterway were near detection limits (from 1 to 9 ug/kg DW).

Chlorinated Benzenes--Only one reported chlorinated benzene concentration exceeded reference conditions in this study: 1,2-dichlorobenzene was detected at 96 ug/kg DW at Station EW-04 in the East Waterway. Detection limits for 1,2-dichlorobenzene were relatively high in the East Waterway (e.g., 100 ug/kg DW at adjacent Station EW-07) and impeded data analysis somewhat in this area. However, the detection limit at nearby Station EW-01 (10 ug/kg DW) indicated that contamination from Station EW-04 was not prevalent at the head of the waterway.

Phthalate Esters--Two phthalate esters were of concern in this study [butyl benzyl phthalate and bis(2-ethylhexyl)phthalate]. Bis(2-ethylhexyl)phthalate was detected frequently (detection frequency = 39/54) but was also observed as a laboratory contaminant in most method blanks. However, concentrations in blanks were relatively low (e.g., equivalent to roughly 50 ug/kg DW). The highest concentrations were observed in the East Waterway (Station EW-14, 930 ug/kg DW, EAR=55). Concentrations at other stations along the east shore of the East Waterway ranged from 110 ug/kg DW (Station EW-15) to 650 ug/kg DW (Station EW-04); the samples with the highest concentrations in the East Waterway were not associated with contaminated method blanks. All other stations in the study had bis(2-ethylhexyl)phthalate concentrations less than 5 times the maximum observed blank concentration (i.e., roughly 250 ug/kg DW).

Butyl benzyl phthalate was detected infrequently (detection frequency = 6/54) and occurred above Puget Sound reference conditions at only three stations: Station EW-01 in the East Waterway (70 ug/kg DW), Station SR-05 (44 ug/kg DW), and Station NG-14 (36 ug/kg DW). Detection limits for butyl benzyl phthalate were 20 ug/kg DW or less throughout the study.

Pesticides--Pesticides were seldom detected in the study, although detection limits in certain samples were relatively high as a result of sample dilution during chemical analysis. Samples with relatively high detection limits included Stations EW-01, EW-04, EW-14, EW-15, and NG-09, which typically had detection limits of 50 to 200 ug/kg DW for individual pesticides. Two of these samples, EW-04 and NG-09, had high PCB concentrations that were likely responsible for GC/ECD interferences. Data analysis for pesticides was not greatly impeded by high detection limits at these five stations because lower detection limits were reported at other stations in these areas. The sole pesticide detection above reference conditions was p,p'-DDT at Station SD-03 (23 ug/kg DW; EAR=2.3). Detection limits for p,p'-DDT at nearby stations ranged from 1 to 10 ug/kg DW.

N-Nitrosodiphenylamine--N-nitrosodiphenylamine was detected seven times over a relatively narrow concentration range. The highest concentration (57 ug/kg DW) was observed at Station EW-01. N-nitrosodiphenylamine was detected at Stations OG-03 through OG-07 at concentrations of 15-38 ug/kg DW. This compound was also detected at 48 ug/kg DW at Station SS-01 and at 28 ug/kg DW at Station SS-06. Other samples with reported concentrations between 10 and 30 ug/kg DW included Stations ES-02, ES-03, NG-06, and SD-01. Detection limits for N-nitrosodiphenylamine were 10 ug/kg DW.

Miscellaneous Extractables and TIO Compounds--Compounds assigned to this class include benzyl alcohol, benzoic acid, dibenzofuran, 2-methylnaphthalene, 1-methylpyrene, retene, a cymene isomer, dibenzothiophene, 1,2,4-trithiolane, a diterpenoid hydrocarbon (possibly dehydroabietane), a diterpenoid alcohol (possibly totarol), hexadecanoic acid, hexadecanoic acid methyl ester, hexadecenoic acid methyl ester, cholesterol, campesterol, an unidentified alkanol, and two isomers with mass spectral base peaks at m/z 181. With the exception of the first four compounds, the chemicals listed above are TIO compounds. TIO compounds are tentatively identified organic compounds found during mass spectral searches of sample extracts; they represent some of the most prevalent peaks in sample chromatograms that were not among the original target compounds. Some, possibly most, of the TIO compounds found in this study are related to target compounds in terms of chemical structure, probable sources, or both. Relationships between target compounds and TIO compounds will be addressed in this section, when applicable.

Several of the miscellaneous extractable organic compounds are closely related to PAH (i.e., 2-methylnaphthalene, 1-methylpyrene, dibenzofuran, and dibenzothiophene). Because these compounds correlated relatively well with PAH, their distribution will not be described here. Correlation coefficients between these compounds and related PAH are as follows: 2-methylnaphthalene vs. naphthalene ($r=0.96$, $n=35$, $P<0.05$); 1-methylpyrene vs. pyrene ($r=0.77$, $n=25$, $P<0.05$); dibenzofuran vs. HPAH ($r=0.95$, $n=44$, $P<0.05$); and dibenzothiophene vs. HPAH ($r=0.96$, $n=19$, $P<0.05$).

Benzoic acid was detected in roughly half of the samples in which it was analyzed and occurred at the highest concentrations in Areas EW and NG (Figure 30). The maximum benzoic acid concentration was reported at Station EW-14 in the East Waterway (5,900 ug/kg DW, EAR=41) but benzoic acid was undetected at nearby stations at detection limits of 200 ug/kg DW or less. Benzoic acid was otherwise undetected throughout the East Waterway, although detection limits were relatively high in most samples (up to 800 ug/kg DW). In Area NG, benzoic acid concentrations were elevated at Stations NG-05, NG-07, and NG-08 (1,300-2,100 ug/kg DW), whereas concentrations were typically at least 5 times lower at other NG stations. Benzoic acid concentrations also exceeded Puget Sound reference conditions at Stations SR-05 (1,000 ug/kg DW), SD-03 (770 ug/kg DW), and ES-03 (760 ug/kg DW; blank-corrected). Of the samples discussed above, only the latter sample was associated with the method blank contaminated at roughly 160 ug/kg DW (see **Sediment Chemistry, Quality Assurance/Quality Control Results** in **Methods** section).

Benzyl alcohol was detected above Puget Sound reference conditions in four samples. The highest concentration was observed at Station EW-04 in the East Waterway (810 ug/kg DW; EAR=81). Detection limits at nearby stations ranged from 20 ug/kg DW to 100 ug/kg DW. Near the mouth of the East Waterway, benzyl alcohol was detected at 58 ug/kg DW (Station EW-11) and at 99 ug/kg DW (Station SD-03). Benzyl alcohol was detected at 42 ug/kg DW at Station SR-05.

Most (14/15) TIO compounds had maximum concentrations in the East Waterway, and 11/15 had maximum concentrations at Station EW-04 (see Table 17).

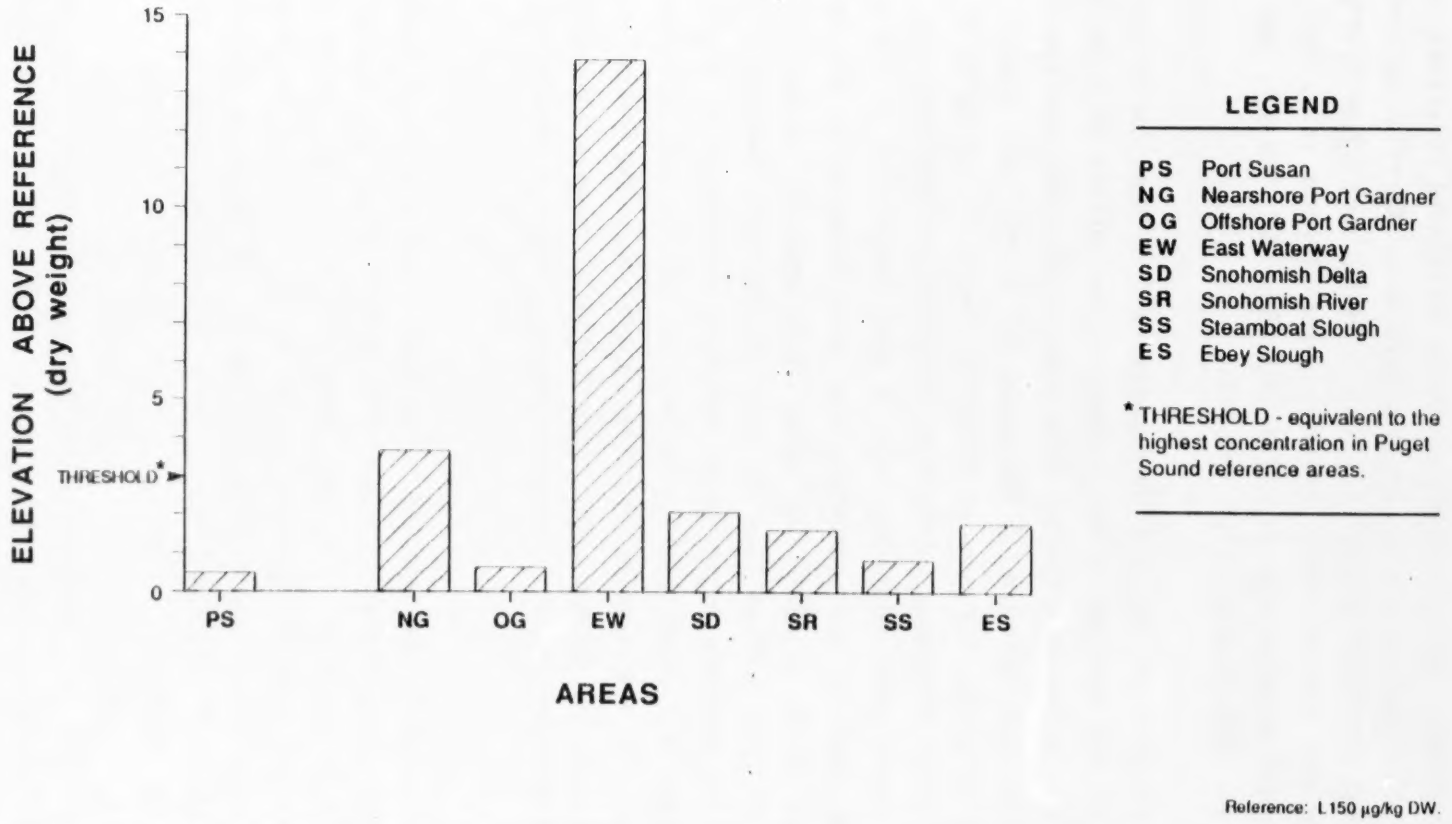


Figure 30. Mean EAR of benzoic acid in sediments from all study areas.

However, some TIO compounds were outstanding in their extreme elevations in the East Waterway relative to other areas. The mean EAR of the following four TIO compounds were over 15 times higher in the East Waterway than in any other study area: retene; a diterpenoid hydrocarbon (possibly dehyroabietane); a diterpenoid alcohol (possibly totarol); and 1,2,4-trithiolane (a sulfur-containing heterocycle). The mean EAR of retene in the East Waterway (39) was 23 times the next highest mean EAR (in Area OG). Within the East Waterway, retene distributions followed a bimodal pattern with concentration maxima at Stations EW-04 and EW-13 (3,100 and 2,900 ug/kg DW, respectively; EAR>100). This distribution pattern was similar to that observed for DHA (Figure 19). The correspondence between DHA and retene ($r=0.99$, $n=20$, $P<0.05$) is not unexpected, as the diagenetic transformation of abietic-type resin acids to retene has been proposed by several researchers (e.g., Simoneit 1986 and references therein; Wakeham et al. 1980; Barnes and Barnes 1983). The structural relationship between retene and DHA is apparent from Figure 15. Retene has previously been detected in marine sediments near pulp mill discharges (Yamaoka 1979; Tetra Tech 1985a). Related sources of retene exist (e.g., brown coal, which can contain fossil resins; Thomas 1970), but are improbable in the East Waterway.

The diterpenoid hydrocarbon TIO compound was highly elevated in the East Waterway (mean EAR=160 in the East Waterway vs. a mean EAR of 5 in Area OG, the next most contaminated area). Within the East Waterway, this compound was predominant at Station EW-04 (23,000 ug/kg DW). The concentration at Station EW-04 was over 10 times the concentration at any other EW station and at least 100 times the concentrations at stations in other study areas. The mass spectrum of this hydrocarbon was similar to that of dehydroabietane (e.g., see spectrum in Kitadani et al. 1970), although other structures are possible. The structural relationship between dehydroabietane and DHA is apparent from Figure 15. In addition, dehydroabietane has been reported in sulfite pulp effluent (Leuenberger et al. 1985) and has been found in sediments near pulp mill discharges (Yamaoka 1979).

The concentration of the diterpenoid alcohol TIO compound also maximized in the East Waterway, but its distribution was different than that of most TIO compounds. The maximum concentration occurred at Station EW-11

(8,600 ug/kg DW), with lower concentrations reported along the east shore of the waterway (e.g., 1,100 to 1,300 ug/kg DW at Stations EW-01, EW-10, and EW-14). Diterpenoid alcohols are structurally related to resin acids (see Figure 15) and have been reported in pulp mill effluents (e.g., Leuenberger et al. 1985; Leach and Thakore 1977). However, the distribution of the diterpenoid alcohol TIO in the East Waterway did not closely correspond to resin acid distributions. Also, the compound was detected at a relatively high concentration away from pulp mill discharges (Station NG-11, 1,100 ug/kg DW). The mass spectrum was similar to that of totarol (a podocarpa-8,11,13-triene derivative).

1,2,4-Trithiolane, a sulfur-containing heterocycle ($C_2H_4S_3$), was most concentrated at Station EW-04 (5,800 ug/kg DW), with lower concentrations at other stations along the east shore of the East Waterway (1,400 to 1,600 ug/kg DW at Stations EW-10 and EW-01). Outside of the East Waterway, detected concentrations were less than 200 ug/kg DW, and typically less than 100 ug/kg DW.

Concentrations of a cymene isomer were highest in the East Waterway at Stations EW-04 (2,900 ug/kg DW) and EW-13 (1,000 ug/kg DW), and were thus consistent with certain resin acid distributions. Concentrations outside the East Waterway were highest in Area OG and were relatively consistent in that area (240 ± 77 ug/kg DW, n=7). Para-cymene has been reported in sulfite pulp mill effluents and is thought to derive from alpha-pinene, a cyclic monoterpene (Leuenberger et al. 1985), although other sources also exist. The isomer (i.e., ortho-, meta-, or para-) observed in this study could not be determined in the absence of standards.

Hexadecanoic acid occurred at the highest concentration in the East Waterway at Stations EW-10 (2,300 ug/kg DW), EW-07 (1,400 ug/kg DW), and EW-11 (1,000 ug/kg DW). Hexadecanoic acid methyl ester and hexadecenoic acid methyl ester both occurred at the highest concentration at Station EW-04, but the concentrations did not exceed an EAR of 10. These fatty acid methyl esters were widespread and occurred over a relatively narrow concentration range throughout the study area. C_{16} and C_{18} fatty acids occur commonly in many organisms and are routinely reported in recent estuarine sediments (along with fatty acid methyl esters). Fatty acids, especially unsaturated C_{16} and C_{18} fatty acids, have been reported as components of pulp mill effluents (e.g., Leach and Thakore 1977) but did not appear to be highly elevated in the East Waterway.

Two sterols were reported as TIO compounds: cholesterol and campesterol. Both compounds had maximum concentrations at Station EW-04 in the East Waterway (cholesterol = 630 ug/kg DW; campesterol = 1,100 ug/kg DW), although concentrations were generally not highly elevated.

Three TIO compounds reported in this study will not be discussed in detail because their identities are not well characterized. The compounds reported as base peak m/z (mass/charge) 181 (isomers 1 and 2) had simple spectra with relatively strong ion intensities at m/z 165, 181, and 210 (the latter was presumably the molecular ion). These compounds, which eluted near one another during GC/MS analysis, both occurred at maximum concentrations at Station EW-04 and had similar distributions overall ($r>0.99$, $n=43$, $P<0.05$). A compound tentatively identified as an alkanol also maximized at Station EW-04, but was widely distributed throughout the study area. This compound had a mass spectrum with a characteristic alkane fragmentation pattern and with no discernible molecular ion. However, the compound was apparently of relatively high molecular weight, as it eluted near d_{12}-benz(a)anthracene (molecular weight = 240) during GC/MS analysis.

Volatile Organic Compounds--Acetone and total xylenes were infrequently detected and occurred only in the East Waterway. Acetone was detected at Stations EW-05 (230 ug/kg DW), EW-06 (140 ug/kg DW), EW-09 (120 ug/kg DW), and EW-07 (83 ug/kg DW). Acetone was undetected at the remaining 15 stations tested with detection limits of 45 ug/kg DW or less. Total xylenes were detected in the East Waterway along a transect of three stations [Stations EW-09 (33 ug/kg DW), EW-08 (39 ug/kg DW), EW-07 (16 ug/kg DW)], and at Station EW-01 (6 ug/kg DW). Detection limits at the other stations tested were less than 25 ug/kg DW.

Comparison with Recent Historical Data

Data from recent studies (1982 to 1987) of Everett Harbor were compiled for comparison to contaminant distributions found in this study and for a more comprehensive assessment of contamination. Data from the following historical studies were compiled:

- Storer and Arsenault (1987) - data from a sediment sampling program conducted as part of the City of Everett CSO control plan development.

- Anderson and Crecelius (1985), Crecelius et al. (1984), and U.S. Army Corps of Engineers (COE) (1985) - data from a series of studies evaluating sediment quality relative to development of the East Waterway port for the Navy

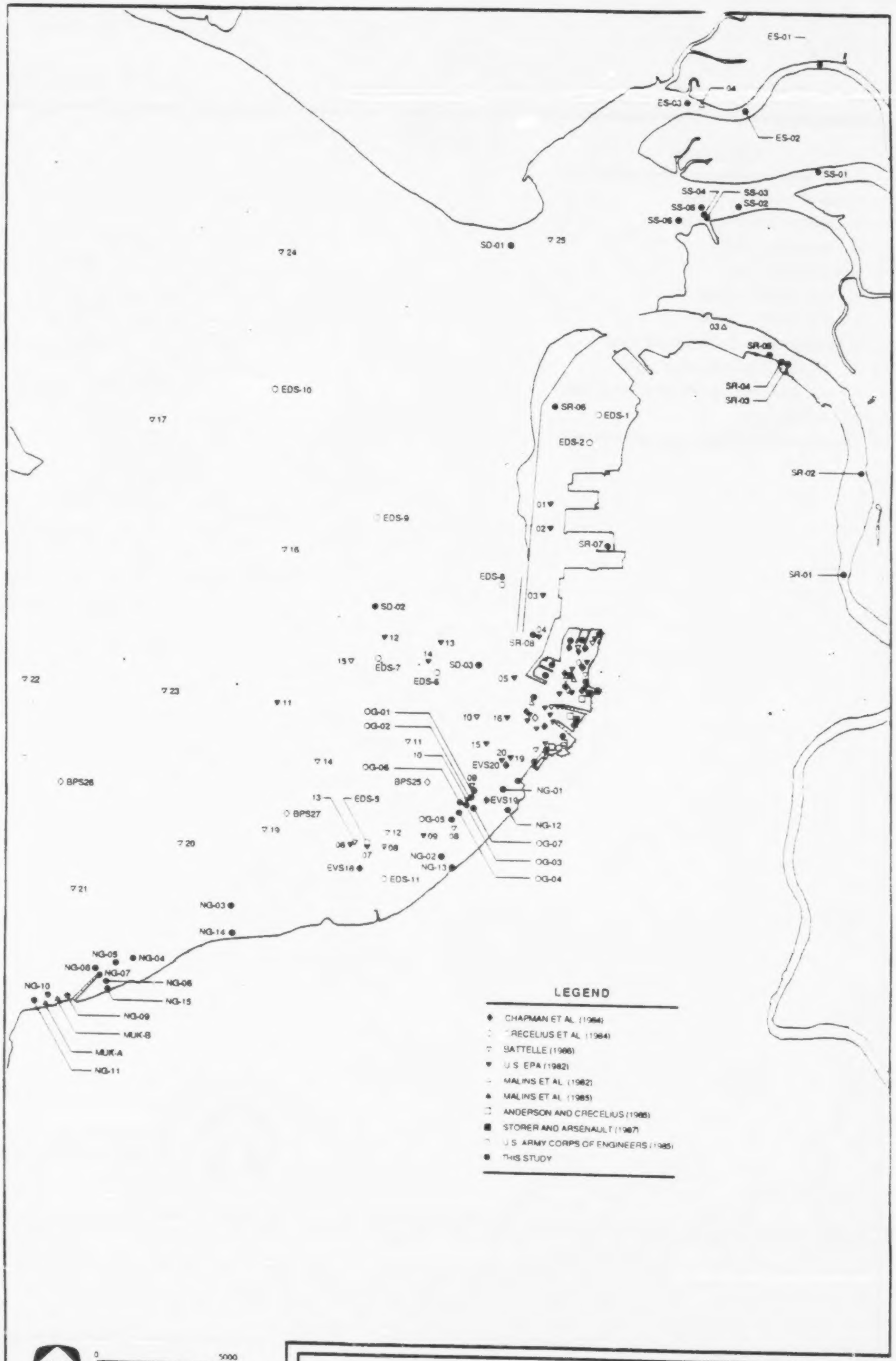
- Battelle Northwest (1986) - a report presenting results of a 2-yr, multiagency study of eight locations in Puget Sound, including Everett Harbor

- U.S. EPA (1982) - unpublished results of sediment chemical surveys of Everett Harbor performed in 1982

- Malins et al. (1982, 1985) - data from three stations located in and near the East Waterway (1982) and from two stations located near Mukilteo (1985)

- Chapman et al. (1984) - data from a survey of biological effects in Everett Harbor, Samish Bay, and Bellingham Bay conducted for the National Oceanic and Atmospheric Administration (only conventional sediment chemistry variables were tested).

Sampling stations from these studies are plotted in Figures 31 and 32. Historical data tended to confirm the distributions reported in the present study in terms of overall trends. However, a number of chemicals that were


ES-01
ES-03
04
ES-02
SS-01
SS-04
SS-03
SS-05
SS-02
SS-06
SD-01
25
24
03
SR-05
SR-04
SR-03
EDS-10
SR-06
EDS-1
EDS-2
17
SR-02
EDS-9
01
02
SR-07
16
SR-01
EDS-8
03
SD-02
SR-08
24
12
13
15
14
EDS-7
SD-03
EDS-6
05
22
23
11
OG-01
OG-02
10
16
11
10
15
20
19
14
OG-06
EVS20
BPS26
BPS25
09
NG-01
13
EDS-5
EVS19
BPS27
OG-05
NG-12
19
12
09
08
06
07
08
OG-07
20
NG-02
OG-03
EVS18
NG-13
EDS-11
OG-04
21
NG-03
NG-14
NG-05
NG-04
NG-08
NG-07
NG-06
NG-10
NG-15
NG-09
MUK-B
MUK-A
NG-11
LEGEND
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▼ U.S. EPA (1982)
MALINS ET AL (1982)
▲ MALINS ET AL (1985)
□ ANDERSON AND CRECELIUS (1985)
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U.S. ARMY CORPS OF ENGINEERS (1985)
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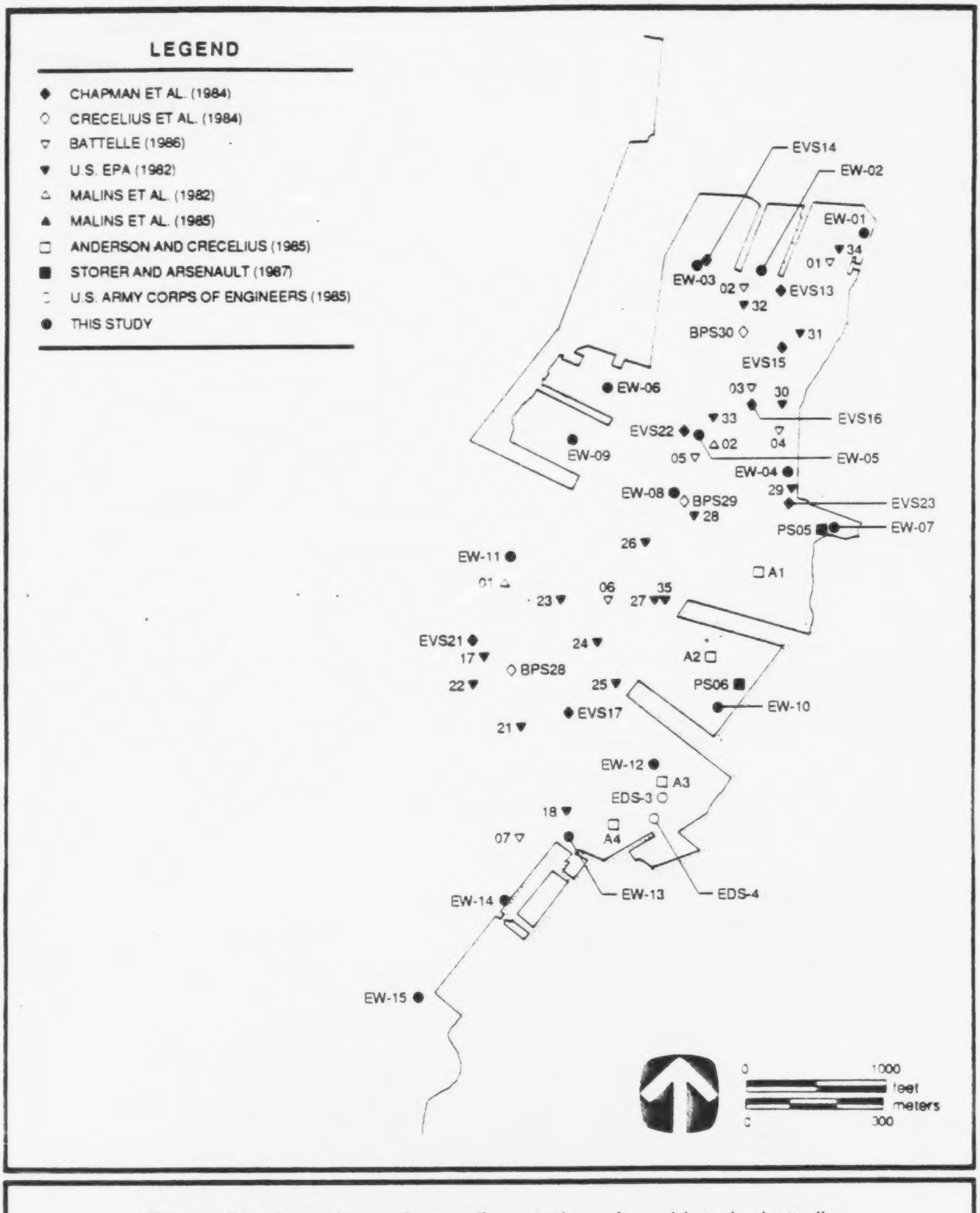
0
5000
feet
meters
0
1500

Figure 31. Locations of sampling stations from historical studies of sediment chemistry in Everett Harbor.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EVS14
EW-02
EW-01
34
01
EW-03
02
EVS13
32
BPS30
31
EVS15
EW-06
03
30
EVS16
33
EVS22
02
04
EW-09
05
EW-05
EW-04
EW-08
BPS29
29
EVS23
28
PS05
EW-07
26
EW-11
A1
01
23
06
35
27
EVS21
24
17
BPS28
A2
22
25
PS06
EW-10
EVS17
21
EW-12
A3
EDS-3
18
07
A4
EW-13
EDS-4
EW-14
EW-15
0
1000
feet
meters
0
300

Figure 32. Locations of sampling stations from historical studies of sediment chemistry in the East Waterway.

most concentrated in the present study (e.g., 4-methylphenol, dehydroabietic acid) were not measured in historical studies. The chemicals detected at high frequencies in historical studies were PAH, PCBs, and metals. Organic EPA priority pollutants were measured by U.S. EPA (1982) but were typically undetected at relatively high detection limits (typically 200 ug/kg DW for A/B/N compounds). In the sections below, historical findings are discussed for metals, PAH, PCBs, and several other chemicals. Phthalate ester and methylene chloride data are not discussed because historical data were not corrected for potential laboratory contamination.

Conventional Variables--

Sulfide and TOC measurements were made during only two of the nine historical surveys. The highest historical concentrations of sulfide and TOC were found in the East Waterway. The maximum historical concentration of sulfides (1,400 mg/kg DW) was measured at Station EDS-3 (U.S. Army COE 1985) along the southeastern shore of the East Waterway. Outside of the East Waterway, sulfide concentrations never exceeded the 210 mg/kg DW value measured at Station EDS-1 in the Snohomish River. The maximum historical concentrations of TOC (25 to 31 percent) were measured at Stations EDS-4 (U.S. Army COE 1985) and A4 (Anderson and Crecelius 1985) in the East Waterway, near Station EW-13 of the present study (23 percent TOC). Outside of the East Waterway, TOC concentrations never exceeded the 4.4 percent value measured at Station EDS-2, located in the Snohomish River.

Metals--

Historical metals data generally supported the results of the present study. The highest metals concentrations were generally measured in the East Waterway. In no case did concentrations of metals of concern exceed the maximum concentration measured in the present study (i.e., at Station EW-14). Historical antimony and mercury data were limited by elevated analytical detection limits. Antimony was undetected at all stations at which it was measured at a maximum detection limit of 4.0 mg/kg DW. Mercury detection limits were 0.4 mg/kg DW for many of the historical samples. Three samples in the East Waterway had mercury concentrations exceeding the maximum reference area concentration; the highest mercury concentration (0.406 mg/kg DW) was observed at Station E-06 (Battelle Northwest 1986).

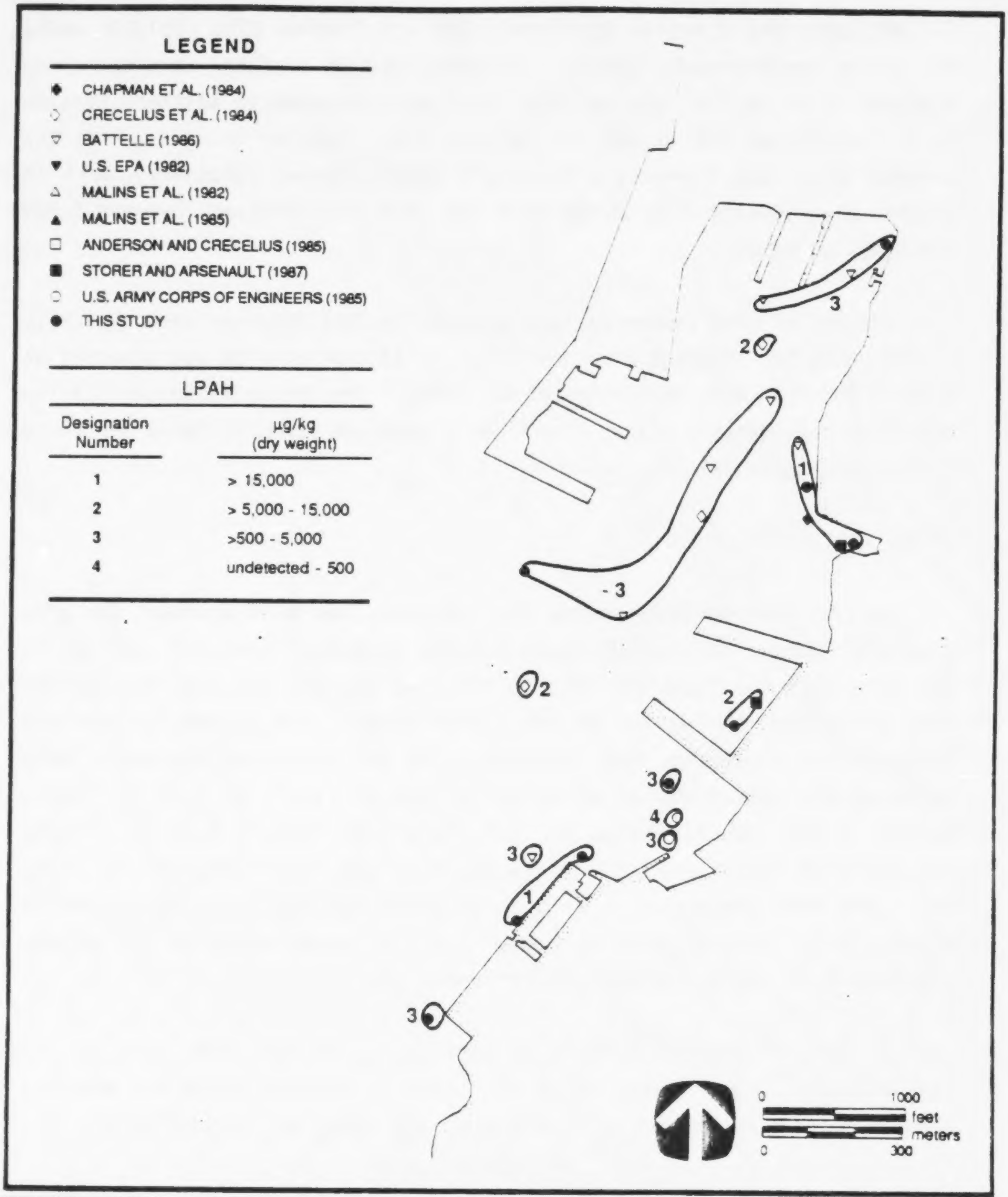
Stations distributed across a relatively broad area exceeded the maximum reference area concentrations for arsenic. Most of these stations were within the East Waterway. However, the highest historical arsenic concentration (46 mg/kg DW) was measured at Station e-11 (U.S. EPA 1982), outside the East Waterway.

The highest historical concentrations of copper and lead (115 and 195 mg/kg DW, respectively) were measured at Station PS05 (Storer and Arsenault 1987), immediately adjacent to Station EW-07 of the present study (copper and lead = 71 and 88 mg/kg DW, respectively). Historical copper concentrations only exceeded the maximum reference area concentration in the East Waterway or in the immediate vicinity of the East Waterway. Historical lead and zinc concentrations exceeded maximum reference area concentrations over the greatest area of metals measured in historical studies. Most of the stations with high concentrations of these metals were located in the East Waterway. However, sediment concentrations of both of these metals exceeded their maximum reference area concentrations throughout the study area. The highest historical concentrations of zinc (1,070-1,210 mg/kg DW) were measured at Stations E-29 (U.S. EPA 1982) and E-04 (Battelle 1986), both near Station EW-04 of the present study (235 mg/kg DW of zinc).

Concentrations of cadmium in historical data sets exceeded the maximum reference area concentration only in the East Waterway. The highest historical concentration of cadmium (4.63 mg/kg DW) was measured at Station BPS-30 (Crecelius et al. 1984).

LPAH--

Historical LPAH data generally supported the results of the present study, but comparisons revealed some spatial heterogeneity of concentrations, especially in the East Waterway (Figure 33). Within the East Waterway, highly contaminated Stations EW-04 and EW-07 (23,000 to 25,000 ug/kg DW) were flanked by historical stations with high concentrations [Station E-04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3
2
1
-3
2
2
3
4
3
3
1
3
0
1000
feet
meters
0
300

LPAH

Designation Number	μg/kg (dry weight)
1	> 15,000
2	> 5,000 - 15,000
3	>500 - 5,000
4	undetected - 500

Figure 33. Contours of LPAH concentrations in East Waterway sediments.

(17,000 ug/kg DW; Battelle Northwest 1986) and Station PS05 (100,000 ug/kg DW; Storer and Arsenault 1987)]. Concentrations of most PAH were extremely elevated at historical Station PS05, even when compared to adjacent Station EW-07, which had EAR >1,000 for several PAH. However, results from the present study and Storer and Arsenault (1987) agreed relatively well in another area (Stations EW-10 and PS06 had LPAH concentrations between 5,200 and 8,100 ug/kg DW).

Historical LPAH concentrations outside the East Waterway were typically <1,500 ug/kg DW, although a concentration of 11,000 ug/kg DW was observed at Station MUK-B in Area NG (Malins et al. 1985). The concentration at Station MUK-B was considerably higher than that at adjacent Stations MUK-A and NG-10 (both 1,200 ug/kg DW).

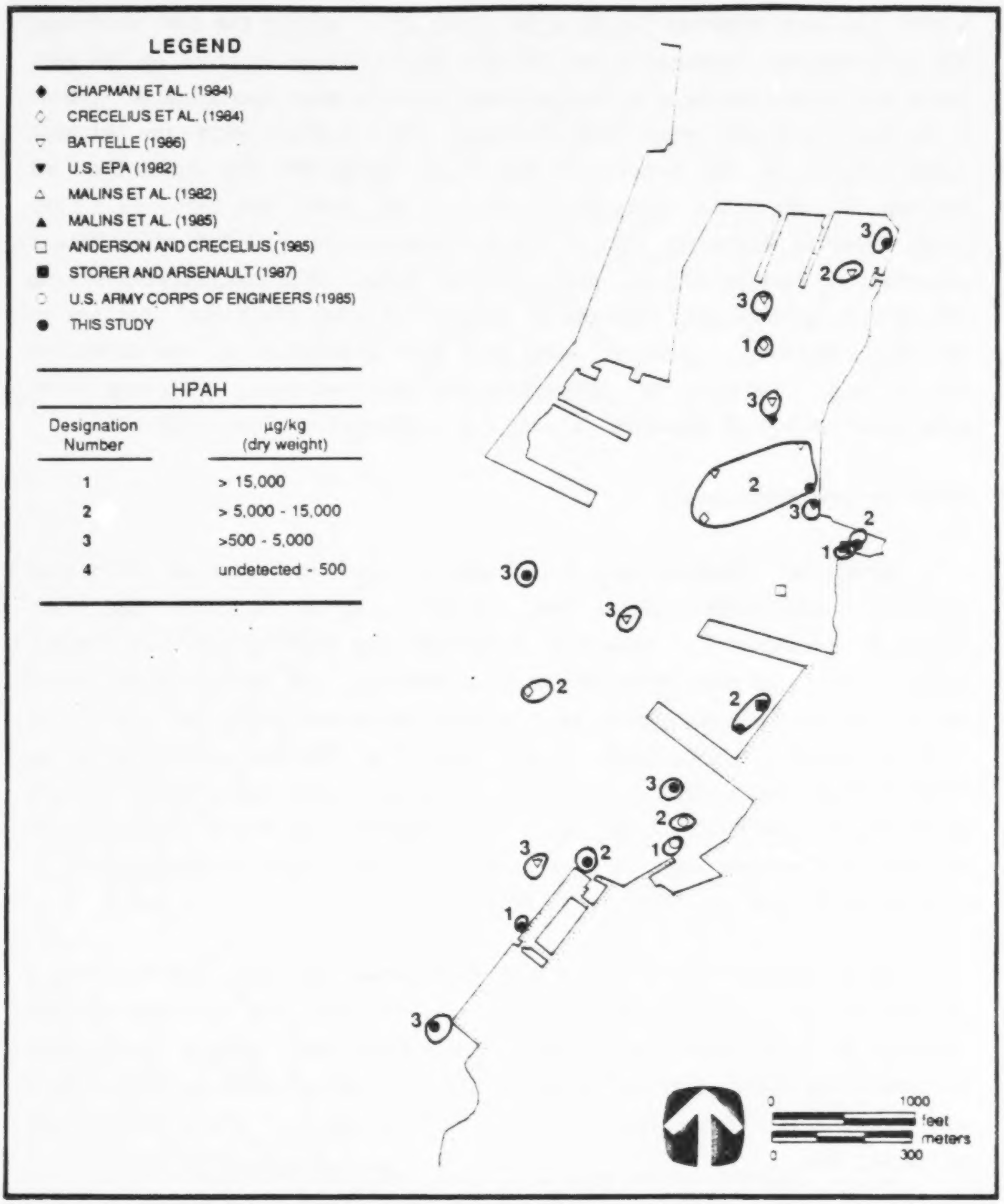
HPAH--

Spatial heterogeneity in the East Waterway was more apparent for HPAH than LPAH (Figure 34). HPAH concentrations at three historical stations in the East Waterway (Stations PS05, EDS-4, and BPS-30) exceeded the maximum HPAH concentration observed in the present study. The extremely high HPAH concentration at Station PS05 (>200,000 ug/kg DW; Storer and Arsenault 1987) exceeded the concentration at adjacent Station EW-07 by over 40 times. Station EDS-4 (46,000 ug/kg DW; U.S. Army COE 1985) had a far higher concentration than adjacent Station EDS-3 of the same study (8,400 ug/kg DW). The HPAH concentration at Station BPS-30 (27,000 ug/kg DW; Crecelius et al. 1984), was over 30 times higher than the concentration at the nearest stations (E-02 and E-03; Battelle Northwest 1986).

Historical HPAH concentrations were typically far lower outside the East Waterway (e.g., <5,000 ug/kg DW), although Stations MUK-B and MUK-A in Area NG had concentrations of 15,000 and 5,700 ug/kg DW, respectively.

PCBs--

PCBs were detected in roughly half of the 67 historical stations at which they were measured. The highest historical PCB concentration occurred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△ MALINS ET AL. (1982)
▲ MALINS ET AL. (1985)
□ ANDERSON AND CRECELIUS (1985)
■ STORER AND ARSENAULT (1987)
○ U.S. ARMY CORPS OF ENGINEERS (1985)
● THIS STUDY
HPAH
1
2
3
0
1000
feet
meters
0
300

Designation Number	µg/kg (dry weight)
1	> 15,000
2	> 5,000 - 15,000
3	>500 - 5,000
4	undetected - 500

Figure 34. Contours of HPAH concentrations in East Waterway sediments.

within the East Waterway (up to 1,000 ug/kg DW). Within the East Waterway, PCB distributions appeared patchy (Figure 35), although stations on the east shore and toward the head of the waterway were the most contaminated. Three historical stations near Station EW-04 (the station with the highest concentration in the present study; 9,600 ug/kg DW) had concentrations between 500 and 1,000 ug/kg DW (Stations E-29, E-03, and E-04) (U.S. EPA 1982; Battelle Northwest 1986). A PCB concentration of 1,000 ug/kg DW was reported at Station BPS-30, north of that area. PCB concentrations from 100 to 650 ug/kg DW were reported at a number of other historical stations in the East Waterway. However, PCBs were also undetected at low detection limits (e.g., 20 ug/kg DW) throughout the East Waterway, including areas with relatively high detected values (e.g., adjacent to Station BPS-30).

Other Organic Compounds--

Phenol was detected only four times in historical studies (detection limits for most historical stations were 200 ug/kg DW) (U.S. EPA 1982), but detected concentrations generally supported the findings of the present study. Along the east shore of the East Waterway, the phenol concentration at Station E-04 (1,400 ug/kg DW; Battelle Northwest 1986) was similar to that at nearby Station EW-04 (2,100 ug/kg DW), and the concentration at Station PS05 (660 ug/kg DW; Storer and Arsenault 1987) was similar to that at nearby Station EW-07 (1,000 ug/kg DW). However, the phenol concentration at Station E-01 was considerably lower than the blank-corrected value at Station EW-01 (250 vs. 1,600 ug/kg DW).

Two historical stations in the East Waterway were analyzed for retene (Malins et al. 1982). The maximum level reported was similar to that observed in the present study (roughly 3,000 ug/kg DW), although the highest concentration observed by Malins et al. (1982; 2,900 ug/kg DW at Station M01) was considerably higher than at nearby Station EW-11 of the present study (62 ug/kg DW).

Total xylenes were detected once in historical studies (Station PS05 in the East Waterway, 140 ug/kg DW; Storer and Arsenault 1987). Total xylenes were detected in the same area during the present study in a cross-waterway

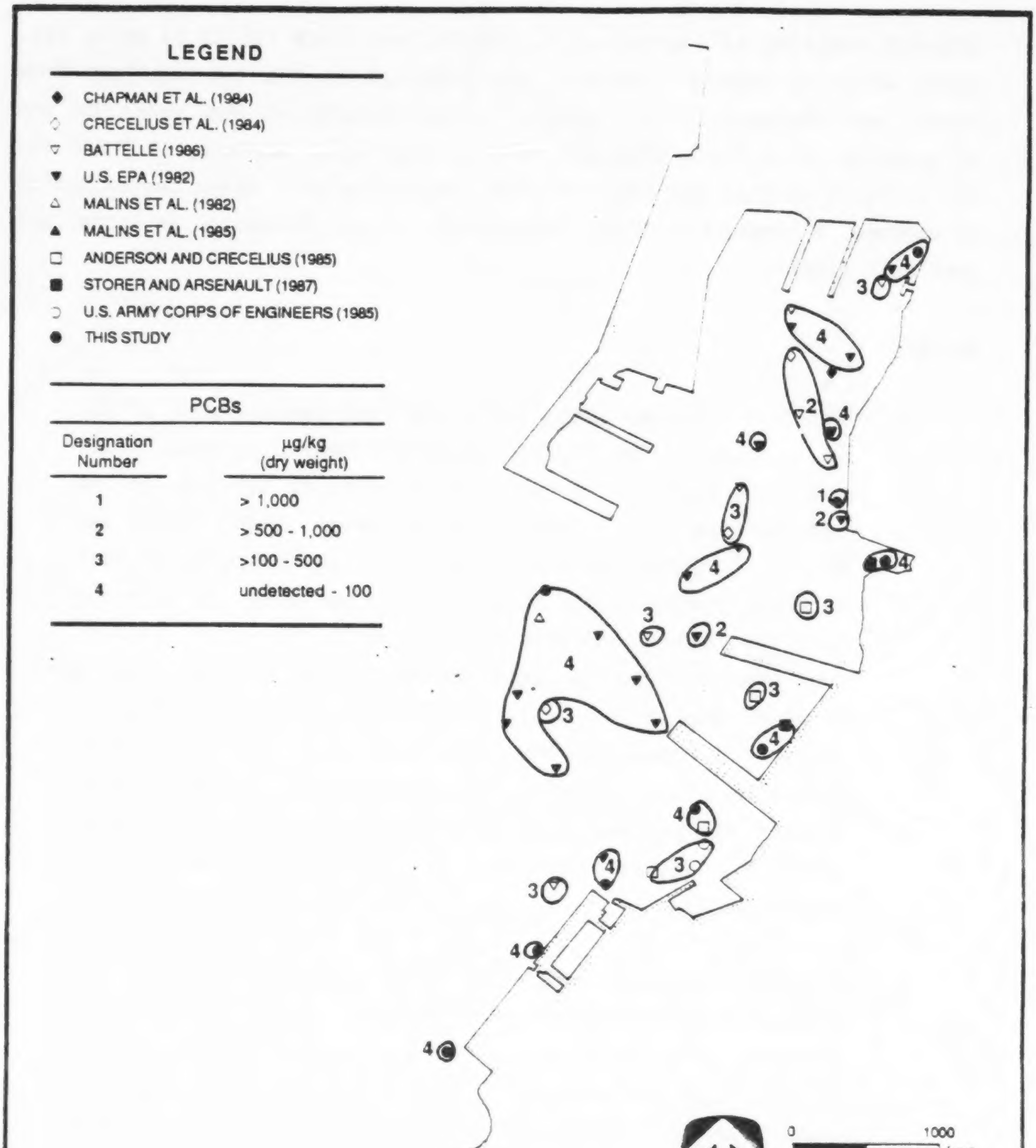

LEGEND
◆ CHAPMAN ET AL. (1984)
◇ CRECELIUS ET AL. (1984)
▽ BATTELLE (1986)
▼ U.S. EPA (1982)
△ MALINS ET AL. (1982)
▲ MALINS ET AL. (1985)
□ ANDERSON AND CRECELIUS (1985)
■ STORER AND ARSENAULT (1987)
○ U.S. ARMY CORPS OF ENGINEERS (1985)
● THIS STUDY
PCBs
Designation Number
µg/kg (dry weight)
1 > 1,000
2 > 500 - 1,000
3 >100 - 500
4 undetected - 100
0
1000
feet
meters
0
300

Figure 35. Contours of PCB concentrations in East Waterway sediments.

transect composed of Stations EW-07, EW-08, and EW-09 (16 to 39 ug/kg DW). Other volatile organic compounds were detected at the two stations from Storer and Arsenault (1987) (e.g., trichloroethene at 400 ug/kg DW and 60 ug/kg DW at Stations PS05 and PS06, respectively; acetone, at 2,800 and 910 ug/kg DW at Stations PS05 and PS06, respectively). Blank contamination by acetone, a common laboratory contaminant, is not documented in Storer and Arsenault (1987).

Summary

- The East Waterway was clearly the most contaminated of all study areas. The highest concentrations of virtually all chemicals measured in the study occurred at stations in the East Waterway (e.g., Stations EW-01, EW-04, EW-07, EW-13, and EW-14, all along the east shore). The predominance of East Waterway contamination relative to other areas is apparent from the summary information in Table 21, in which stations are characterized by 90th percentile exceedances for a diverse range of chemicals. More moderate contamination in terms of concentrations and complexity of contaminant assemblages was observed in offshore and nearshore Port Gardner study areas (i.e., Areas OG and NG) and at other relatively isolated stations (e.g., Station SR-05 in the Snohomish River).

- Organic compounds were much more widely distributed at elevated concentrations than metals. Among the organic compounds with the highest detection frequencies and reported at the highest concentrations were 4-methylphenol (maximum concentration = 98,000 ug/kg DW; EAR=7,500), dehydroabietic acid (maximum concentration = 83,000 ug/kg DW; EAR=1,300), abietic acid (maximum concentration = 98,000 ug/kg DW; EAR=650), PAH (naphthalene in particular; maximum concentration = 17,000 ug/kg DW; EAR=3,000), and several tentatively identified organic compounds (most notably, a diterpenoid hydrocarbon thought to be dehydroabietane; maximum concentra-

TABLE 21. NUMBER OF CHEMICALS OF CONCERN EXCEEDING 90TH PERCENTILE CONCENTRATIONS[a]

Station	Metals	PAH[b]	Resin Acids	Phenols/ Guaiacols	PCBs/ Pesticides	Miscellaneous Extractables/ TIO Compounds	Phthalates	Nitrogen-Containing Compounds	Volatile Organic Compounds
ES-01	1								
EW-01	3		1	8		4	1	1	
EW-02				4					
EW-03				1					
EW-04	4	16	6	8	1	14	1		
EW-05				1					1
EW-07	5	9	2	3	1	6			1
EW-08									1
EW-10	4	2		2		6	1		
EW-11		1				6			
EW-12						1			
EW-13	4	16	3	2		7	1		
EW-14	6	17		1		6	1		
EW-15		2				2			
NG-01						1			
NG-03						1			
NG-04						1			
NG-05						1			
NG-07						1			
NG-08						1			
NG-09		9		1	1	2			
NG-11		10				1			
NG-14						1	1		
NG-15	1								
OG-03						1			
OG-06						1			
SD-03					1				
SR-05							1		
SR-07	2								
SS-01								1	

[a] Stations not shown did not have any chemicals exceeding 90th percentile concentrations. Chemicals exceeding 90th percentile concentrations but not exceeding Puget Sound reference area concentrations were not included. Chemicals included in each group are listed in Tables 14 and 17.

[b] Includes LPAH and HPAH as groups as well as individual PAH.

tion = 23,000; EAR>1,000). Other organic compounds occurred at high concentrations at relatively isolated stations [e.g., PCBs (maximum concentration) = 9,600 ug/kg DW (EAR=1,600)]. All of the compounds mentioned above occurred at maximum concentrations along the east shore of the East Waterway. Metals concentrations were highly elevated at a single station in the study (Station EW-14 in the East Waterway), particularly for zinc (5,910 mg/kg DW; EAR=310), copper (1,010 mg/kg DW; EAR=160), and arsenic (685 mg/kg DW; EAR=200). Outside the East Waterway, 4-methylphenol was most elevated over the widest area of any measured chemical.

- Historical sediment chemistry data generally supported the findings of the present study, although considerable spatial heterogeneity was apparent for HPAH and PCBs in the East Waterway. Notably, available historical studies did not provide data for the organic compounds found at the highest concentrations in the present study (especially 4-methylphenol, dehydroabietic acid, and abietic acid) or for distinctive geochemical tracers of the pulp industry observed in the present study (especially chlorinated derivatives of compounds occurring in coniferous woods, such as chlorinated resin acids and chlorinated guaiacols).

BIOACCUMULATION

Bioaccumulation studies were conducted to determine if selected contaminants were accumulated in the tissues of indigenous organisms in the Everett Harbor study area. The contaminants selected for analysis (PCBs, mercury, and 12 chlorinated pesticides) have a high potential for accumulation in higher organisms such as fishes and crabs. Previous studies in Everett Harbor have also indicated that PCBs may be bioaccumulated at concentrations exceeding reference levels. The objective of the present study was to describe the geographic trends in bioaccumulation and to determine whether tissue contaminants in the Everett Harbor study area were elevated above concentrations observed at the Port Susan reference area.

Mercury in Dungeness Crabs

Mercury concentrations in edible muscle tissue of Dungeness crabs (Cancer magister) are presented in Figure 36. In general, mercury concentrations were relatively homogeneous and low throughout the study area, ranging from 0.042 to 0.130 mg/kg wet weight. Although tissue concentrations in crabs from the East Waterway and Port Gardner shoreline were slightly higher than at the Port Susan reference area, the maximum elevation above reference was only 2.0 at Station EW-92. Crabs from the lower Snohomish River and Snohomish River Delta areas had slightly lower mercury levels than crabs from the reference area. Because sampling was not replicated at each station, tests of the statistical significance of the observed differences were not performed.

PCBs and Pesticides in Dungeness Crabs

All 12 pesticides measured were undetected in the crab samples from the Everett Harbor study area. Detection limits for these substances ranged from 0.1 to 0.8 ug/kg wet weight.

PCB concentrations in Dungeness crabs from the Everett Harbor study area are presented in Figure 36. PCBs were detected in crab muscle samples from all stations except SD-91. Because of low analytical recoveries (see **Bioaccumulation, Quality Assurance/Quality Control Results** in **Methods** section), all PCB data are considered potential underestimates of actual PCB levels. In addition, the crab tissue data were not replicated at any station except EW-91. Because of these limitations, no statistical analyses were conducted to determine among-station differences. Instead, the data are used only for relative comparisons of PCB levels among sampling sites.

The highest average PCB level measured in crabs (24 ug/kg wet weight) was 4.7 times higher than the reference level and was measured at Station NG-92 near Mukilteo. Lower PCB concentrations (i.e., 0.7 to 2.4 times the reference level) were measured along the south Port Gardner shoreline and in the lower Snohomish River. Crabs collected from the three Snohomish River delta sites had PCB concentrations equal to or less than the reference level.

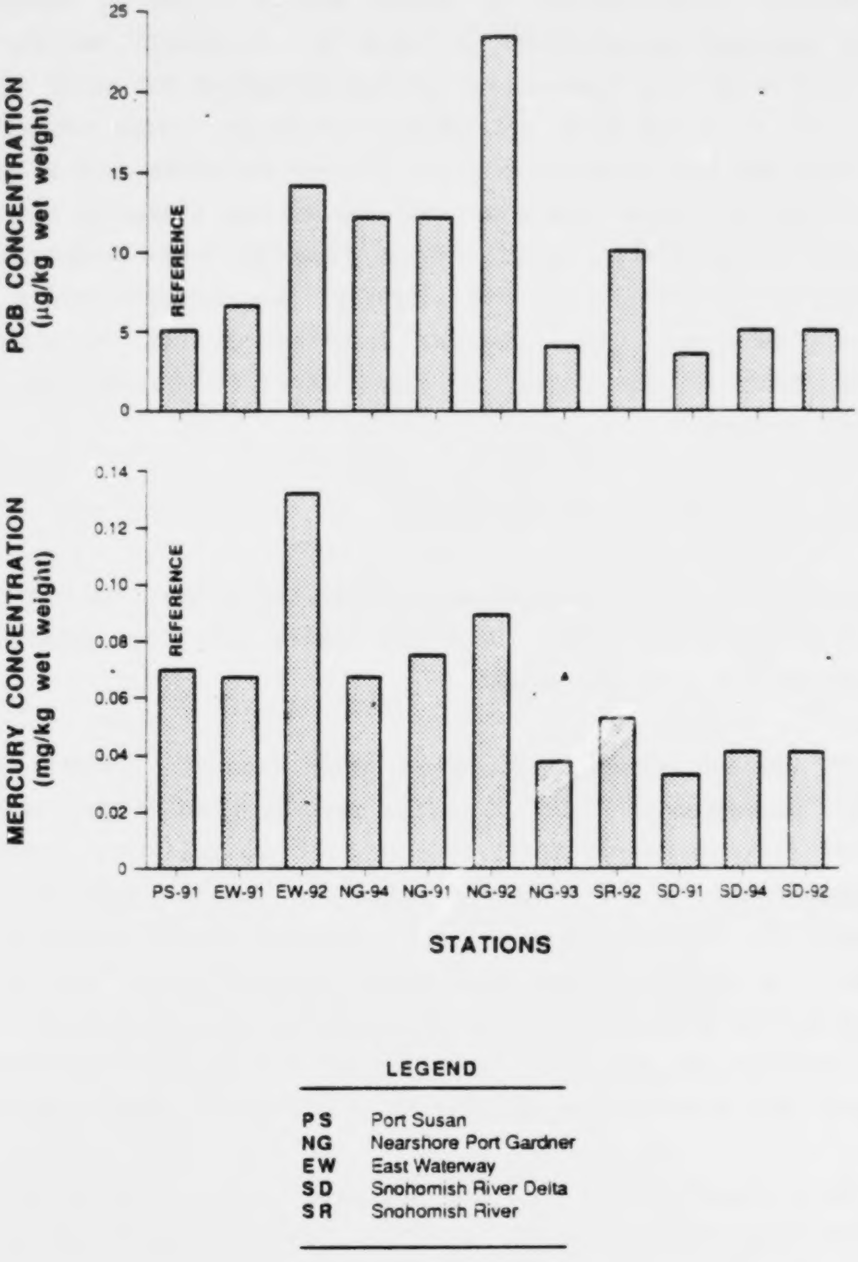


Figure 36. Concentrations of PCBs and mercury in Dungeness crab muscle tissue samples from Everett Harbor and Port Susan.

As discussed in the **Methods** section, the PCB tissue data did not meet the minimum 50 percent surrogate recovery levels specified by PSEP (Tetra Tech 1986g). Recovery of a surrogate compound (DBOFB) can be used, however, to calculate an estimated PCB concentration that may be more representative of actual PCB levels than the low-recovery measurements for this study. Although a single surrogate compound cannot accurately represent recovery of all 209 possible PCB congeners, previous performance tests performed by Battelle (PTI and Tetra Tech 1988) indicated that DBOFB recoveries were similar to overall recoveries of spiked PCB mixtures. For Station NG-92, the DBOFB recovery was 36 percent, resulting in a theoretical maximum PCB concentration in crabs of 67 ug/kg wet weight (i.e., 2.78 X 24 ug/kg). The corresponding reference level in crabs corrected for DBOFB recovery was 18 ug/kg wet weight. Similar applications of surrogate recovery corrections for the other sampling stations did not result in any calculated average PCB levels exceeding 61 ug/kg wet weight. Therefore, using this approach, the maximum calculated EAR for PCBs in crab tissue is 3.7 at Station NG-92.

Mercury in English Sole

Mercury concentrations in English sole (Parophrys vetulus) edible muscle tissue from Everett Harbor are presented in Figure 37. In general, mercury concentrations were relatively homogeneous throughout the study area. The highest average mercury levels (0.067 mg/kg wet weight) were measured at the Port Susan reference area. Mean concentrations of mercury in English sole samples from Everett Harbor ranged from 0.010 to 0.062 mg/kg wet weight, with no evidence of mercury bioaccumulation above reference levels.

The relationship between mercury concentrations and muscle lipid content was examined to determine if differences in lipid content were influencing the bioaccumulation results. These analyses showed a statistically significant negative correlation between total extractable organic matter (a measure of lipid content) and mercury concentration ($r=-0.34$, $n=54$, $P<0.01$). Thus, fish with higher lipid contents tended to have lower mercury levels. The lipid content of English sole from the reference area (8.6 mg/kg wet weight) was intermediate in the range of values for the Everett Harbor area (6.7 to 15 mg/kg wet weight). Based on the relatively

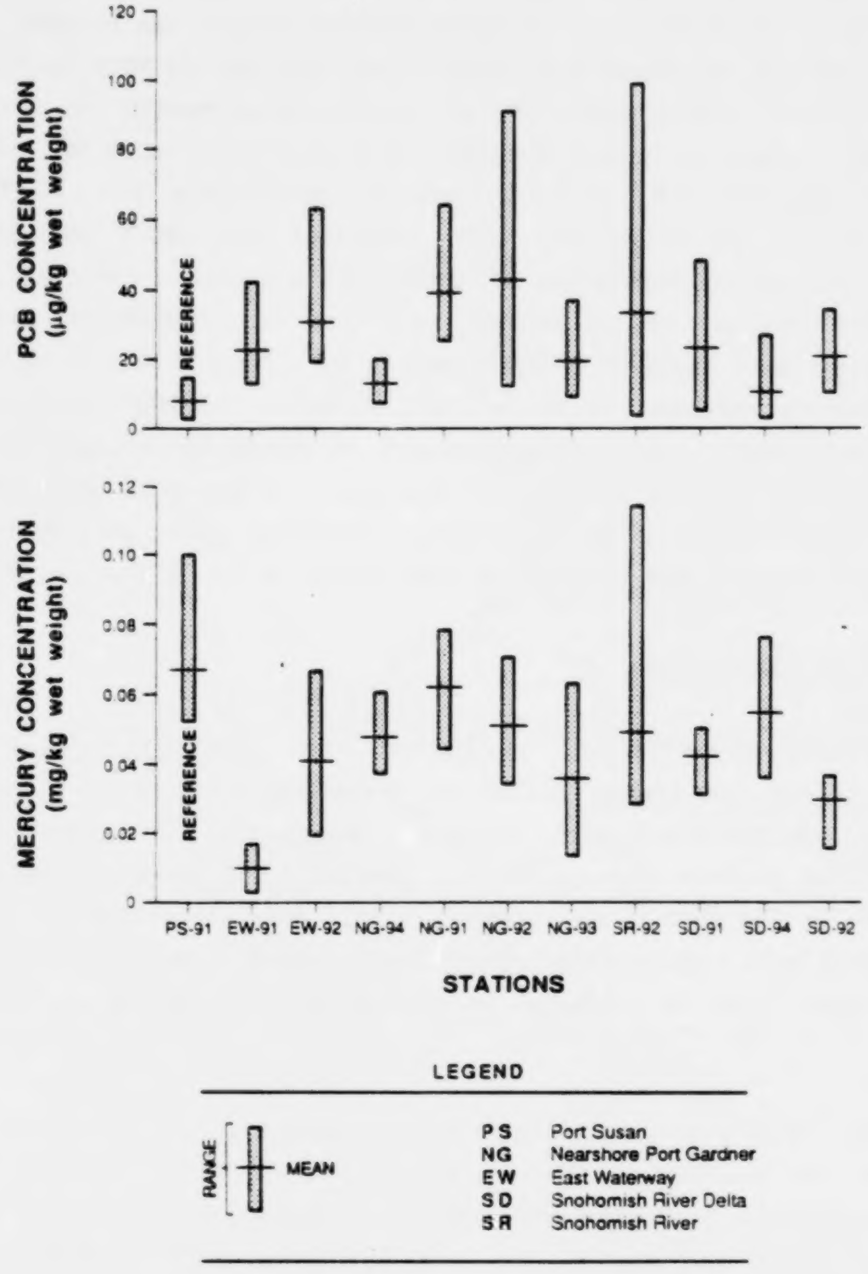


Figure 37. Concentrations of PCBs and mercury in English sole muscle tissue samples from Everett Harbor and Port Susan.

low correlation of these variables, the relatively constant mercury concentrations, and the intermediate lipid levels at the reference site, it does not appear that major differences in mercury concentrations among sampling stations are due to differences in lipid content.

PCBs and Pesticides in English Sole

None of the 12 pesticides measured were detected in any of the English sole tissue samples. The detection limits ranged from 0.1 to 0.8 ug/kg wet weight for these analyses.

PCB concentrations in English sole muscle tissue samples are presented in Figure 37. The mean PCB concentrations (as averages for five individual fish) ranged from a minimum of 8.3 ug/kg wet weight at the reference site to a maximum of 43 ug/kg wet weight at Station NG-92 near Mukilteo. The EAR for measured concentrations ranged from 1.3 on the Snohomish Delta to 5.1 at Mukilteo. Overall, the maximum value for an individual fish (99 ug/kg wet weight) was measured in the lower Snohomish River. PCBs were detected in all but two of the individual samples analyzed (detection limit of 3.5 ug/kg wet weight).

The PCB data for English sole were characterized by the same low surrogate recoveries as the crab data. The data should therefore be considered as potential underestimates of actual PCB levels. The surrogate recoveries were relatively consistent among sampling sites (most were 25 to 36 percent). Therefore, the data are probably accurate representations of the relative magnitudes of PCB tissue concentrations among sampling sites. For Station SR-92, the average DBOFB recovery was 26 percent, resulting in a theoretical maximum PCB concentration in fish tissue at this sampling station of 130 ug/kg wet weight (i.e., 3.85 x 34 ug/kg). The corresponding reference level in sole corrected for DBOFB recovery was 35 ug/kg wet weight. Similar applications of surrogate recovery corrections for the other sampling stations did not result in any calculated average PCB levels exceeding 120 ug/kg wet weight. Therefore, using this corrective approach, the maximum calculated EAR for PCBs in fish muscle tissue was 3.7 at Station SR-92.

There was no statistically significant correlation between the muscle lipid content of English sole and tissue concentration of PCBs ($r=0.21$, $n=54$, $P>0.05$). The concentrations of total extractable organic matter were also similar between the reference site (8.6 mg/g wet weight) and Station SR-92 (9.6 mg/g wet weight). Therefore, it does not appear that any differences in lipid content were influencing apparent differences in PCB levels among sampling sites.

Comparison with Recent Historical Data

Historical data on bioaccumulation in fishes and crabs from the Everett Harbor study area are very limited. The only available data on bioaccumulation in English sole muscle tissue are in Cunningham (10 November 1982, personal communication). In this study, PCB levels in English sole muscle tissue ranged from 49 to 190 ug/kg wet weight in samples from the East Waterway, Snohomish River, and Gedney Island. The maximum concentration was measured in a sample from the Snohomish River. The PCB data are similar to the PCB levels measured in the present study, especially when the latter data are corrected for low surrogate recoveries. The maximum PCB level measured was slightly higher than the maximum theoretical level calculated for this study (130 ug/kg wet weight) (Cunningham, D., 10 November 1982, personal communication).

Summary

- For both Dungeness crabs and English sole, none of the 12 measured pesticides were detected in edible muscle tissue from the Everett Harbor study area.
- Mercury concentrations in edible muscle tissue from Dungeness crabs and English sole from the Everett Harbor study area were similar to, or less than, mercury levels in organisms from the Port Susan reference area.
- Interpretation of PCB data was limited by low analytical recoveries. Measured PCB levels were generally higher in

Dungeness crabs and English sole from the Mukilteo area, the Snohomish River, and the East Waterway than in the Port Susan reference area. However, the maximum theoretical concentrations of PCBs (after adjustment for surrogate recoveries) in crab and fish samples were not elevated substantially above the reference area levels (i.e., maximum EAR of 3.7) and were low when compared to other urban embayments in Puget Sound.

- PCB levels measured in crabs and fish in this study were similar to levels measured in a previous study in Everett Harbor.

SEDIMENT BIOASSAYS

The results of sediment toxicity tests using the amphipod Rhepoxynius abronius are presented in this section (see Appendix D for data listing). First, amphipod bioassay results for Port Susan are compared with results from other reference areas used during previous studies. The amphipod mortality values for each station in the Everett Harbor system are then presented and compared statistically with the Port Susan values. Finally, results of the present study are compared with those of previous studies on the toxicity of Everett Harbor sediments to R. abronius.

Evaluation of the Reference Area

Mean values of amphipod survival and their 95 percent confidence limits are shown in Figure 38 for individual stations in Port Susan and other reference areas of Puget Sound. Data for the 1985 survey of Port Susan, which were collected as part of the Elliott Bay Toxics Action Program, are also shown in the figure. Mean amphipod survival for several of the Port Susan observations was low (<80 percent) relative to data for most other reference areas. Mean survival was also low ($\leq$75 percent) at one station in Carr Inlet, where a single replicate was an extreme outlier, and at one station in Sequim Bay. The relatively low survival at some Port Susan stations cannot be explained by a response of the amphipods to fine-grained sediments. The product-moment correlation between mean amphipod survival

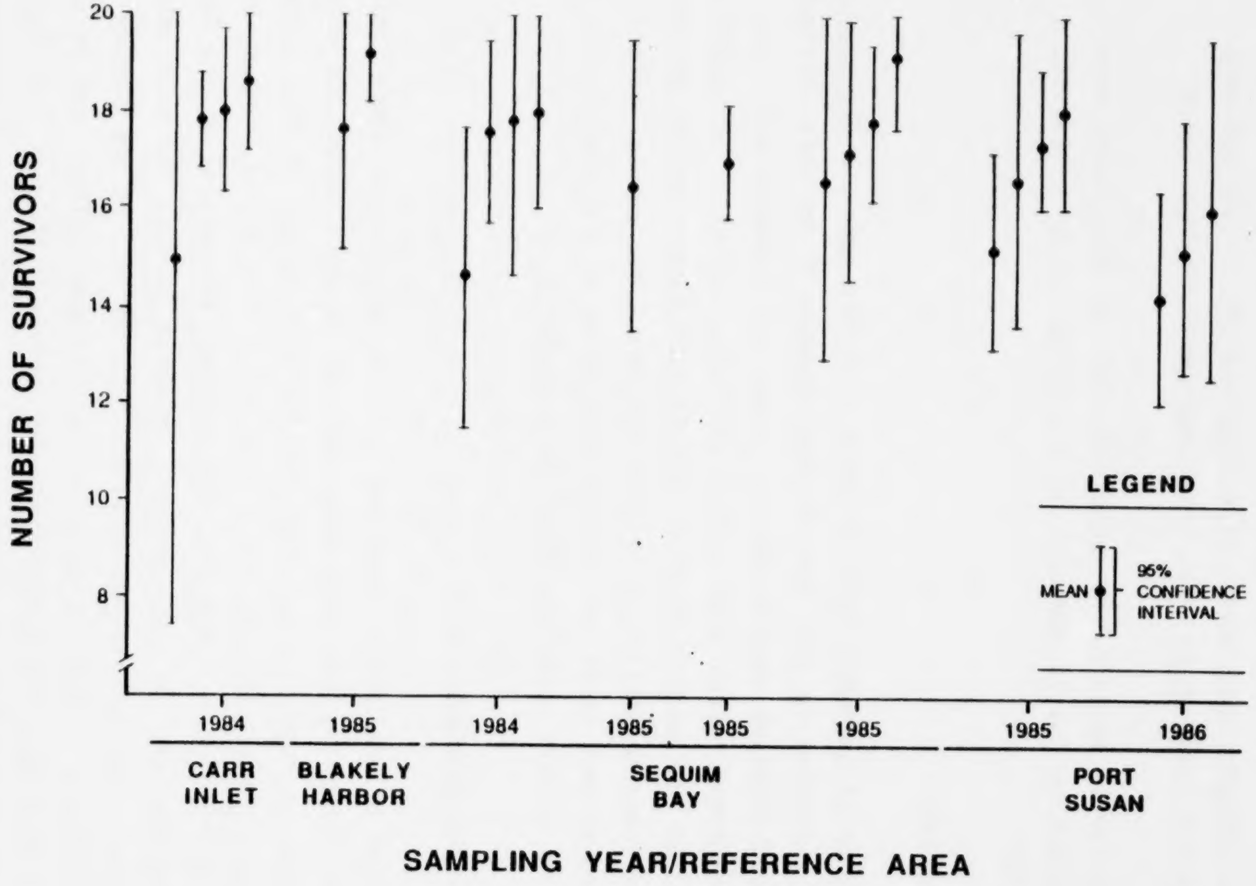


Figure 38. Amphipod bioassay data from Puget Sound reference areas.

and percent fine-grained material at Port Susan stations was not significant (r=0.38, n=7, P>0.05). The range of percent fine-grained material in samples collected during 1985-1986 in Port Susan was 7.4-88 percent. Only a single sample contained more than 24 percent fine-grained material. Moreover, mean amphipod survival for that sample (Station PS-01, 1985) was relatively high (87 percent).

The 1986 data for amphipod response to Port Susan sediments include one station (PS-02) where mean survival (71 percent) indicated that the sediment was toxic based on a toxicity threshold value (i.e., survival ≤76.4 percent) derived in an extensive interlaboratory comparison by Mearns et al. (1986). Consequently, the 1986 data from this station were unacceptable for use as reference data and were excluded from further analyses. The 1986 data for amphipod response to Port Susan sediments at Stations PS-03 and PS-04 are considered marginally adequate for use as reference data. The mean survival of amphipods exposed to sediments collected from these two stations during 1986 was 78 percent. Nevertheless, Everett Harbor sites were compared statistically with Port Susan rather than the West Beach (Whidbey Island) control site because the latter is the natural habitat of the amphipods used in this study. Use of a separate reference area (Port Susan) minimizes the possible bias due simply to removal of amphipods from their native habitat and placement in a non-native sediment. Moreover, Port Susan appears to be an adequate reference area based on data for other indicators (see results for sediment chemistry, bioaccumulation, benthic infauna, and fish pathology). Contaminant concentrations in sediments at Stations PS-03 and PS-04 were typically within the range of those observed at other reference areas in Puget Sound and were low relative to Puget Sound AET (see above, **Sediment Chemistry**). Therefore, the 1986 bioassay data from Stations PS-03 and PS-04 were used for statistical comparisons with data from sites in the Everett Harbor system.

General Patterns of Amphipod Mortality

The mean amphipod mortality and the range of station-specific means for each study area within the Everett Harbor system and the reference area (1986) are shown in Figure 39. The highest overall mortalities were found

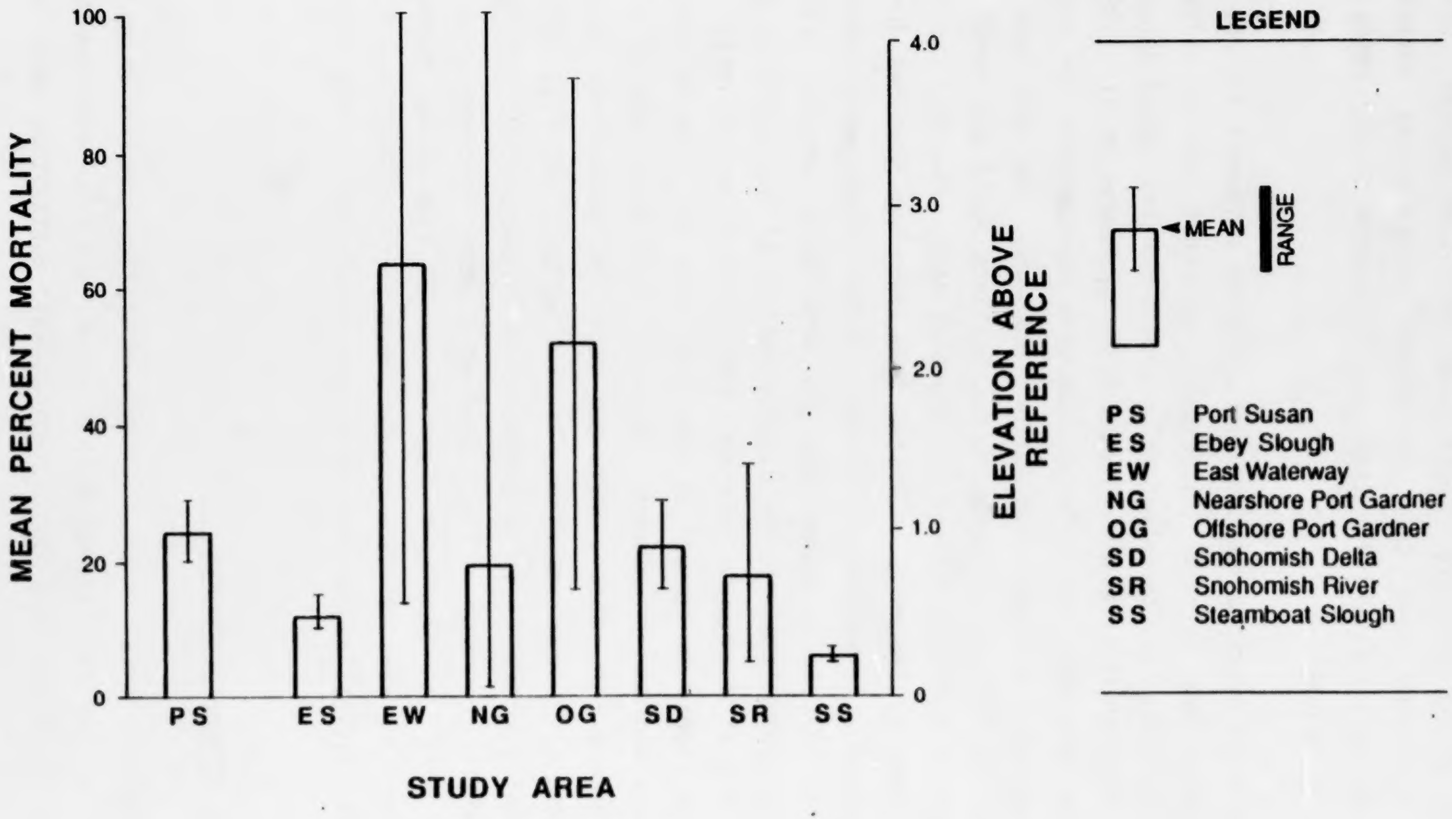


Figure 39. Mean and range of amphipod bioassay responses within study areas.

in the East Waterway (mean mortality = 63 percent). Total mortality (100 percent) was observed at Stations EW-01 and NG-04. The range of mean mortality at stations within the East Waterway and Nearshore Port Gardner study areas (the most intensively sampled areas) was large, indicating considerable spatial heterogeneity. Some stations within each area exhibited mean mortality values less than or equal to the values for Stations PS-03 and PS-04 in Port Susan.

Comparison of the Everett Harbor System with Port Susan

Results of the amphipod bioassay tests for all stations sampled during the Everett Harbor investigation are summarized in Table 22. Statistical comparisons between Everett Harbor sites and the reference area (Port Susan 1986, Stations PS-03 and PS-04 pooled) indicated that mean mortalities for four test sediments were significantly different from the Port Susan samples ($P<0.001$). Three of these toxic sediments were from the East Waterway; one was from Nearshore Port Gardner near the defense fuel storage depot at Mukilteo (Figure 40).

At three of the seven stations that exhibited a mean amphipod mortality ≥ 40 percent, mean mortality was not statistically different from the mean reference value at $P<0.001$. However, these stations (EW-10, NG-06, and OG-03) did exhibit a significant difference from the reference area at $P<0.05$. The lack of significance at $P<0.001$ for mean mortality values over 40 percent at some stations can be explained by low statistical power, partly due to the relatively high mean mortality in the reference area. Also, the variance of the bioassay test is typically higher at intermediate mortality values (35-65 percent) compared with the extremes of the mortality range. The variance of the mean was very high [standard deviation ≥ 28, corresponding to a standard error ≥ 12] at three stations: Stations EW-10, OG-03, and SR-07. The relative influence of reference mortality vs. variability on the statistical power of the amphipod bioassay is being investigated in a separate EPA project on refinement of sediment quality values.

TABLE 22. SUMMARY OF AMPHIPOD BIOASSAY RESULTS

Station	Range of Mortality (percent)	Mean Mortality[a] (percent)
ES-01	0-20	10(4.2)
ES-02	5-25	12(3.7)
ES-03	0-25	15(4.2)
EW-01	100[b]	100(0)*
EW-04	95-100	99(1.0)*
EW-07	60-100	75(8.4)*
EW-10	10-100	55(19)
EW-12	10-20	13(2.0)
EW-14	15-55	37(7.2)
NG-01	0-10	5(1.6)
NG-02	0-15	6(2.4)
NG-03	5-15	13(2.0)
NG-04	100[b]	100(0)*
NG-06	25-55	43(5.6)
NG-10	0-10	5(1.6)
NG-12	0-10	2(2.0)
NG-13	0-10	6(1.9)
NG-14	0-10	5(2.2)
NG-15	0-5	1(1.0)
OG-03	15-90	58(12)
PS-02	20-40	29(4.0)
PS-03	15-40	24(4.6)
PS-04	5-35	20(6.3)
SD-01	5-20	15(3.2)
SD-02	15-50	29(7.0)
SR-01	0-35	12(6.0)
SR-02	0-10	4(1.9)
SR-04	15-30	21(2.9)
SR-07	0-80	33(13)
SR-08	0-30	15(5.7)
SS-01	0-10	5(2.2)
SS-03	0-10	6(2.4)
Control[c] A	0-10	5(2.2)
Control B	0-25	10(4.2)
Control C	5-15	9(1.9)
Control D	0-10	4(1.9)

[a] Mean mortality is based on five replicate samples per station. Standard error of each mean is given in parentheses.

[b] A mortality level of 100 percent was observed for each of the five replicates.

[c] Clean control sediments from the amphipod collection site at West Beach, Whidbey Island.

* Asterisk denotes that mean mortality differed significantly ($P<0.001$) from the mean mortality of pooled replicates from two Port Susan stations (PS-03 and PS-04).

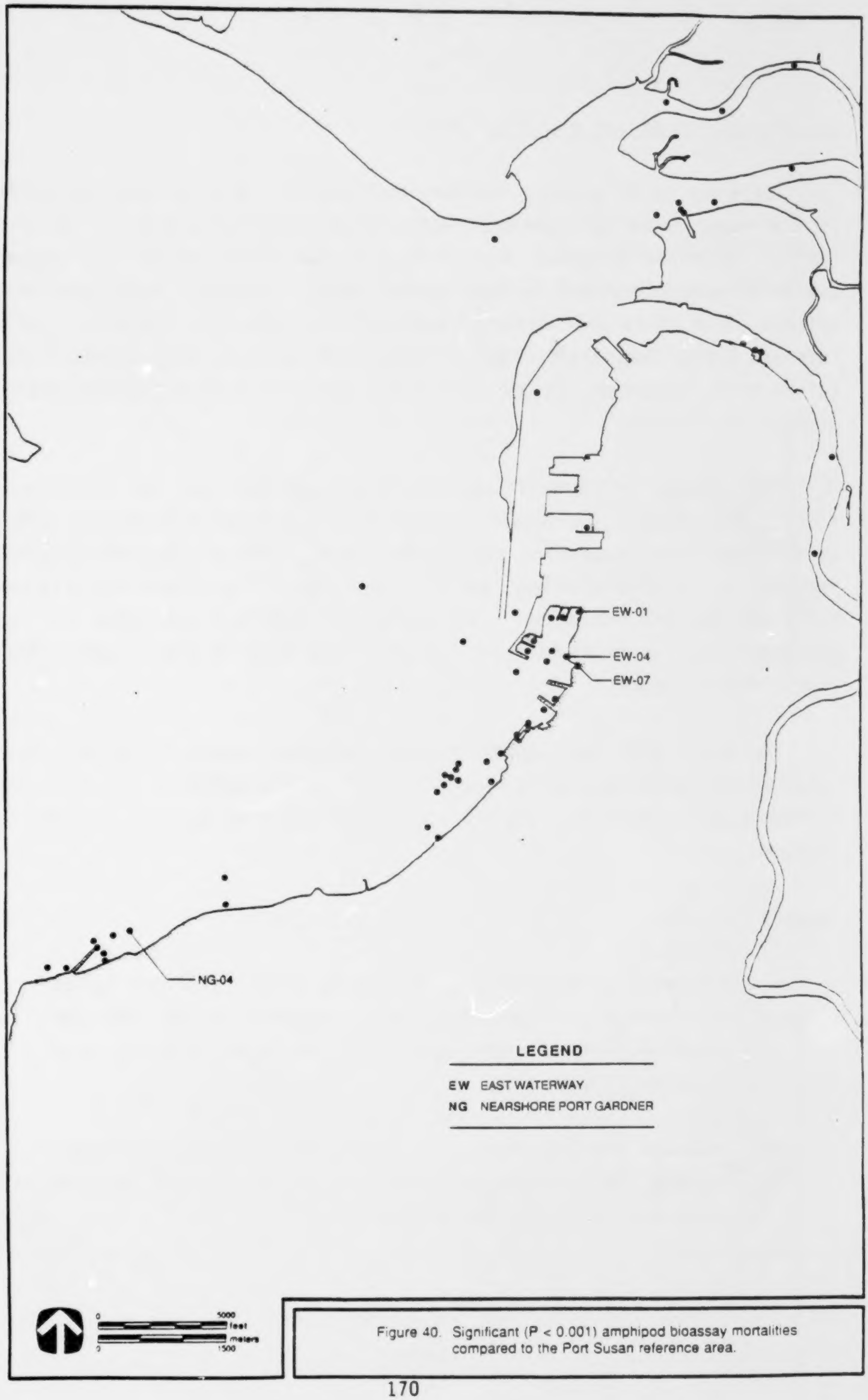

EW-01
EW-04
EW-07
NG-04
LEGEND
EW EAST WATERWAY
NG NEARSHORE PORT GARDNER
0
5000
feet
meters
0
1500

Figure 40. Significant ($P < 0.001$) amphipod bioassay mortalities compared to the Port Susan reference area.

Comparison with Recent Historical Data

There are no R. abronius sediment bioassay test data for Everett Harbor in the Puget Sound Environmental Atlas (Evans-Hamilton and D. R. Systems 1987). Amphipod bioassay data from previous tests of Everett Harbor sediments were summarized by Long (unpublished). However, these data were obtained from tests that deviated substantially from PSEP protocols (Tetra Tech and E.V.S. Consultants 1986). Either the sediments were stored frozen before being tested or, in one case (i.e., Battelle Northwest 1986), tested without replication.

The results of unreplicated amphipod bioassays must be interpreted cautiously. However, it should be noted that the Battelle Northwest (1986) data support the results of the present study. The highest toxicity was recorded in the East Waterway near a station where significant toxicity was found in the present study. No historical data are available for the Mukilteo area, where significant toxicity was found in the present study (i.e., Station NG-04).

The U.S. Army COE (1985) tested composite samples from the East Waterway and found relatively high toxicity in these sediments. Because the sediments were composited, the magnitude of toxicity at specific stations is unknown.

Summary

- Sediments from 4 of the 29 Everett Harbor stations tested displayed significant toxicities ($P<0.001$) in the amphipod bioassay when compared with the Port Susan reference area (Figure 40) (Table 22)

- Although previous data are limited, there was good agreement between the present study and results of previous amphipod bioassays in Everett Harbor

- The most toxic area in Everett Harbor was the East Waterway. Significant toxicity was also found at one station near Mukilteo (Station NG-04).

BENTHIC MACROINVERTEBRATES

The purposes of this section are to describe the general characteristics of benthic communities in Everett Harbor and the Port Susan reference area, and to identify areas where benthic communities may be impacted. Characterization of the benthic communities within Everett Harbor is based on the abundance and distribution of individual taxa and the major infaunal taxonomic groups (i.e., polychaetes, pelecypods, gastropods and crustaceans). Identification of potentially impacted areas is based on comparisons of benthic community indices among Port Susan and Everett Harbor stations including major taxa abundance, species richness, abundance of dominant taxa, pollution-tolerant or opportunistic taxa, and similarity of species distributions.

The following discussion is organized into several major topics. First, the adequacy of the reference area (Port Susan) is evaluated. Second, the general characteristics of infaunal communities within Everett Harbor and in Port Susan are described, and abundances of major taxonomic groups are compared statistically to identify areas of impact. Third, species level data are used to characterize each station and refine the identification of the type of stress that may be impacting the benthic community. Individual stations or areas within Everett Harbor that appear to be degraded and the degree of the apparent degradation are then discussed. Finally, comparisons are made with historical data.

Evaluation of the Reference Area

The ideal reference area for any investigation of anthropogenic effects would be identical to the potentially impacted area, but would lack all anthropogenic influences. This condition is not achievable because no two areas are exactly alike naturally, and because most areas exhibit some evidence of human activities. Nevertheless, a reference area should possess as many characteristics in common with the study area as possible, with the exception of anthropogenic impacts, to allow unbiased comparisons between areas. In this investigation, Port Susan was selected as the reference area for benthic communities in Everett Harbor based the following characteristics:

- It has a major riverine input (i.e. Stillaguamish River) similar to that of the Snohomish River in Everett Harbor

- It does not have any major sources of contamination other than possible slight organic enrichment from the Stillaguamish River

- It exhibits a range of sediment grain sizes similar to most stations sampled in Everett Harbor

- It is adjacent to the Everett Harbor study area and is likely to share similar benthic fauna and physical influences (e.g. currents, weather patterns). .

Port Susan is an extremely productive estuary, indicating that ample sources of nutrients are available to support the biota. The Stillaguamish River may potentially be a source of nutrient enrichment in Port Susan, as much of the river's watershed is agricultural. However, the sediment data collected during both the 1985 Elliott Bay investigation (where Port Susan was used as the reference area) and this survey do not show evidence of organic enrichment in Port Susan.

Grain-size characteristics of the sediments at stations in Port Susan appear to have been affected slightly by their distance from the mouth of the Stillaguamish River. Station PS-04 (furthest from the river mouth) consisted of coarse sandy sediments, whereas Station PS-02 (closest to the river mouth) consisted of fine sandy sediments (see Appendix E). Other conventional sediment variables (i.e., nitrogen, total organic carbon, total solids) also exhibited slight gradients in relation to the distance from the river (see Appendix E).

Sediments at stations sampled in other selected reference areas in Puget Sound are also predominantly sandy (Table 23). Mean concentrations of total organic carbon, sulfides, and total solids at the Port Susan stations were similar to those documented in the other reference areas listed in Table 23, and appear to be typical of unimpacted areas.

Abundances of the major benthic taxonomic groups at the Port Susan stations were also similar to those in other reference areas within Puget Sound. Mean total abundances and mean abundances of polychaetes, molluscs, and crustaceans were generally similar to mean abundances observed in Carr Inlet, Blakely Harbor, Central Puget Sound (15-22 m depths), and at Port Susan stations sampled in 1985 (Figure 41).

Comparisons of mean total abundances and mean abundances of the major benthic macroinvertebrate taxa groups in Port Susan between 1985 and 1986 revealed differences between years (Figure 41). Mean total abundances were significantly ($P \leq 0.05$) lower in samples collected in 1986 than in 1985. Mean abundances among the major taxonomic groups were lower in 1986, reflecting the decrease in total abundance, but the differences between years were not statistically significant ($P > 0.05$) for any major taxonomic group.

Examination of the five most abundant taxa at each station in Port Susan indicated that species composition was fairly similar both within and between years (Table 24). Two to four species at each station were also among the abundant taxa at the other stations in Port Susan. This high degree of similarity documents that structurally similar assemblages of benthic macroinvertebrates were sampled at all three stations in Port Susan in 1986, and suggests that those assemblages were temporally stable. Comparisons of the five most abundant species at the 1985 and 1986 Port Susan stations with those at the Carr Inlet stations reveals little similarity between these two areas (Table 24). This is not unexpected, however, because Port Susan and Carr Inlet are located in different regions of Puget Sound and exhibit different habitat characteristics (e.g., exposure, freshwater input).

TABLE 23. SURFACE SEDIMENT CHARACTERISTICS AT BENTHIC INFAUNA STATIONS IN PORT SUSAN COMPARED WITH OTHER REFERENCE AREAS IN PUGET SOUND

Reference Area	Sediment Type[a]	Mean TOC (%)	Mean Sulfide (mg/kg)	Mean Total Solids (%)	Depth Range (m)
Port Susan (1985)[b]	sand-clayey silts	0.78	22.8	66.4	10-12
Port Susan (1986, this study)	sand	0.34	U[c]	77.4	11-12
Carr Inlet[d]	sand	0.41	2.3	70.4	2-26
Blakely Harbor[e]	sand	1.65	~15	67.8	10-18
Central Puget[f] Sound (Seahurst)	sand	1.51	--	--	15-22
Samish Bay[g]	silty sand/ clayey silt	1.65	--	--	10-30
Case Inlet[g]	sandy silt	2.2	--	--	21-41
Sequim Bay[g]	sandy silt	2.35	--	--	19-26

[a] Sediment type designations after Shephard (1954).

[b] Data from PTI and Tetra Tech (1988).

[c] Undetected at a detection limit of 6 mg/kg dry weight.

[d] Data from Tetra Tech (1985a).

[e] Data from Tetra Tech (1986d).

[f] Data from Word et al. (1984).

[g] Data from Battelle (1986).

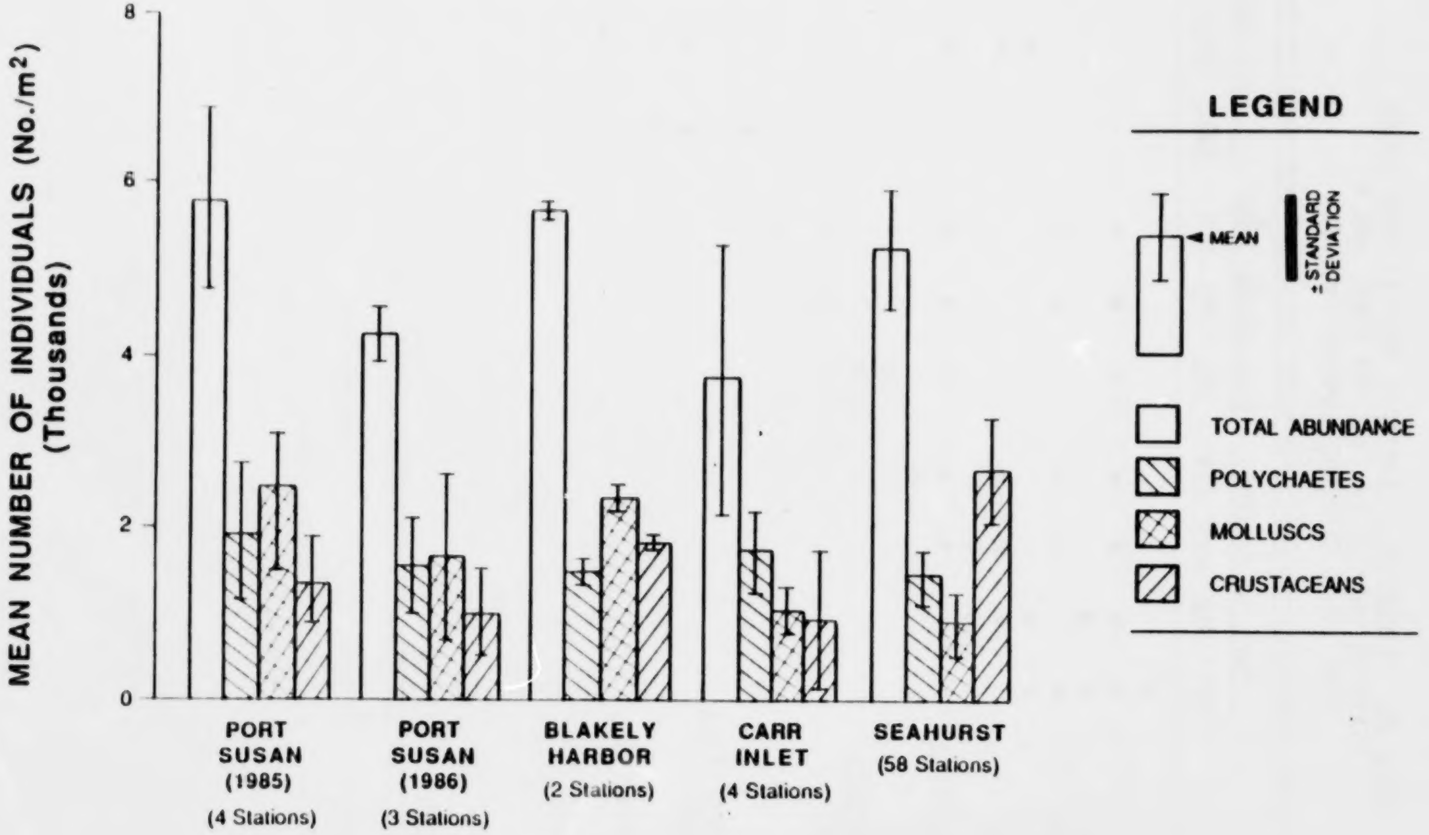


Figure 41. Mean total abundances (no./m^2) and mean abundances of major taxonomic groups of benthic invertebrates in Puget Sound reference areas.

TABLE 24. NUMERICALLY DOMINANT TAXA AT PORT SUSAN STATIONS SAMPLED IN 1985 AND 1986, AND AT CARR INLET STATIONS SAMPLED IN 1984

	Port Susan 1985				Port Susan 1986			Carr Inlet 1984			
	PS1	PS2	PS3	PS4	PS2	PS3	PS4	CR11	CR12	CR13	CR14
Protomedia prudens	■										
Psephidia lordi	■	■	■	■	■	■	■				
Terebellides stroemi	■	■									
Euphilomedes producta	■		■	■		■	■				
Lumbrineris spp.	■	■							■		
Axinopsida serricata		■	■	■	■				■	■	
Lumbrineris luti		■	■								
Euphilomedes carcharodonta			■	■	■	■	■		■		
Ampharete acutifrons				■							
Clinocardium nuttali					■						
Leitoscoloplos pugetensis					■						
Pectinaria granulata						■	■				
Macoma baltica						■					
Pista spp.							■				
Leptochelia dubia								■			
Phyllochaetopterus prolifica								■			
Prionospio steenstrupi								■	■	■	
Odostomia spp.								■		■	
Platynereis bicanaliculata								■			
Amphioda urtica									■		
Scalibregoma inflatum										■	■
Mitrella gauldi										■	
Macoma nasuta											■
Caprellidae											■
Caprella mendax											■
Spiophanes berkelyorum											■

Opportunistic and pollution-tolerant taxa (as defined by Pearson and Rosenberg 1978) constituted an average 28.2 percent of the fauna at the stations in Port Susan (Table 25). In Carr Inlet 21.8 percent of the fauna was represented by those same taxa. *Prionospio steenstrupi*, *Macoma nasuta* and *Euphilomedes carcharodonta* constituted most of the opportunistic and pollution-tolerant organisms in Carr Inlet, accounting for 14.7 percent of the total population. *Euphilomedes carcharodonta* and *E. producta* were abundant at stations in Port Susan, and accounted for nearly all of the opportunistic and pollution-tolerant taxa at those stations. *Euphilomedes* spp. are known to increase in abundance in areas where slight to moderate organic enrichment has occurred (Word et al. 1977). Because *Euphilomedes* spp. are common in areas of only moderate enrichment, these taxa may not be a strong indicator of benthic community stress. Therefore if abundances of *Euphilomedes* spp. are not considered in the foregoing calculations, opportunistic and pollution-tolerant organisms would have constituted <12.0 percent of the benthic macroinvertebrates at all stations in Port Susan, and 19.3 percent of the benthic macroinvertebrates in Carr Inlet. Thus, abundances of opportunistic and pollution-tolerant taxa in Port Susan were low, and appeared to be comparable to Carr Inlet.

Overall, the foregoing comparisons of conditions in Port Susan in 1986 with conditions in other reference areas in Puget Sound, and with Port Susan in 1985, affirm the adequacy of Port Susan as a reference area for benthic macroinvertebrate communities in Everett Harbor. Sediment grain-size characteristics, the values of other conventional sediment variables, and abundances of the major taxonomic groups of benthic invertebrates at the three Port Susan stations were similar to those in other reference areas. The similarity between the numerically dominant taxa collected at the three Port Susan stations sampled in both 1985 and 1986 further indicates that the structure of the benthic assemblages in Port Susan may be temporally stable. Finally, abundances of opportunistic and pollution-tolerant taxa were found to be low, and comparable to the Carr Inlet reference area.

TABLE 25. RELATIVE ABUNDANCES (PERCENT TOTAL FAUNA) OF OPPORTUNISTIC AND POLLUTION-TOLERANT TAXA[a] AT STATIONS IN PORT SUSAN AND CARR INLET[b]

Taxon	Stations PS-02	PS-03	PS-04	Carr Inlet[c]
Euphilomedes carcharodonta (Os)[d]	8.3	17.6	16.7	2.9
Euphilomedes producta (Os)	1.3	6.0	10.5	0.1
Glycinde picta (Po)	0.0	0.2	0.0	0.5
Goniada brunnea/maculata (Po)	0.3	0.6	0.7	0.1
Leitoscoloplos pugettensis (Po)	5.3	3.4	0.9	1.6
Macoma balthica (Pe)	1.6	6.0	0.0	0.2
Macoma nasuta (Pe)	0.0	0.0	1.0	3.2
Mediomastus spp. (Po)	0.5	<0.1	<0.1	1.6
Nephtys cornuta franciscana (Po)	0.0	0.0	0.0	0.7
Paraprionospio pinnata (Po)	0.0	0.0	0.0	0.7
Prionospio steenstrupi (Po)	0.3	0.5	0.7	8.6
Scololplos armiger (Po)	0.5	0.1	<0.1	0.0
Others	0.7	0.3	0.9	1.9
(No. of taxa)	(6)	(3)	(7)	(6)
Total	18.8	34.7	31.4	21.8

[a] As defined by Word et al. (1977), Pearson and Rosenberg (1978), and Word (1980).

[b] Data from Tetra Tech (1985a).

[c] Mean value of four stations.

[d] Os=Ostracoda, Po=Polychaeta, Pe=Pelecypoda.

Justification of Use of Pooled Port Susan Data

In this study, impacts to the benthos were inferred using statistical criteria to identify changes in the abundances of the major taxonomic groups of benthic invertebrates. When comparing benthic communities in potentially impacted areas with those in reference areas, it is often advisable to stratify between-station comparisons by habitat characteristics. Because sediment grain size is an important determinant of benthic community structure (Sanders 1960; Johnson 1971; Gray 1974; Fresi et al. 1983), it can be used to define the strata.

Sediments in Everett Harbor exhibited a wide variety of textural characteristics, that ranged from clayey silts to coarse sands (Figure 42). In many areas of Everett Harbor, the sediments showed evidence of anthropogenic inputs, and can no longer be considered representative of "natural" conditions. Typically, these sediments smelled of hydrogen sulfide or petroleum, or both. Wood chips were common in the grab samples, as was scrap metal, oil droplets, and other debris. Field notes indicate that over half the stations sampled in Everett Harbor exhibited evidence of sediment modification (e.g., hydrogen sulfide, petroleum, foreign objects). Largely because of these anthropogenic modifications, the entire spectrum of sediment characteristics in Everett Harbor is not present in Port Susan.

The previous evaluation of Port Susan as a reference area and an a priori examination of the sediment characteristics and benthic community structure in Everett Harbor indicated that:

- Total abundances and abundances of the major taxonomic groups of benthic invertebrates in Port Susan were comparable to abundances in other reference areas in Puget Sound, despite differences in species composition

- Species composition among Port Susan stations was temporally stable between 1985 and 1986

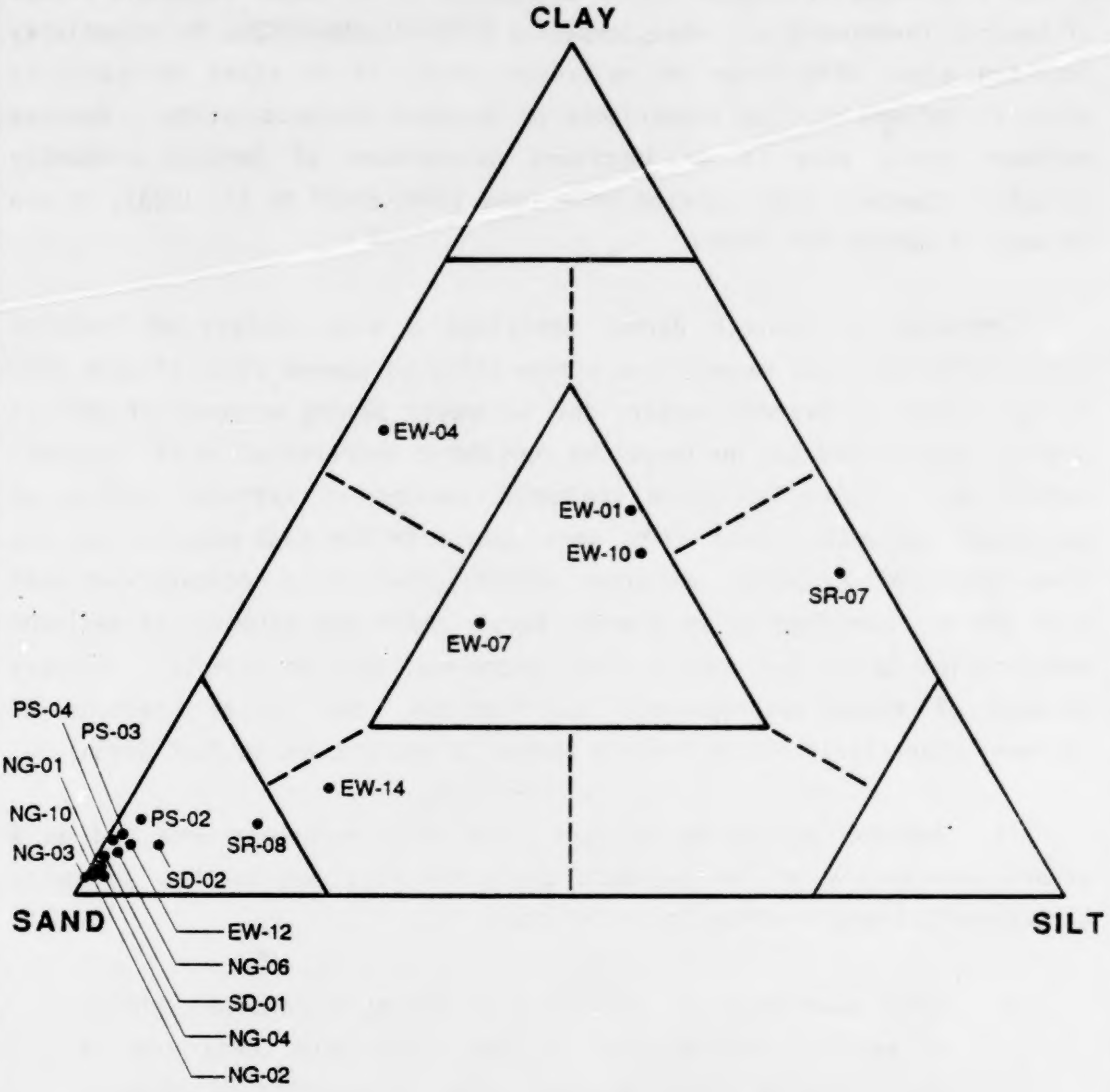


Figure 42. Sediment grain size characteristics at benthic infauna stations in Everett Harbor and Port Susan (1986).

- Species composition of dominant taxa among Port Susan stations was very similar

- Sediment characteristics among the three Port Susan stations were very similar

- The sediments in Everett Harbor are highly modified in many cases, and many sediment characteristics cannot be "matched" in Port Susan.

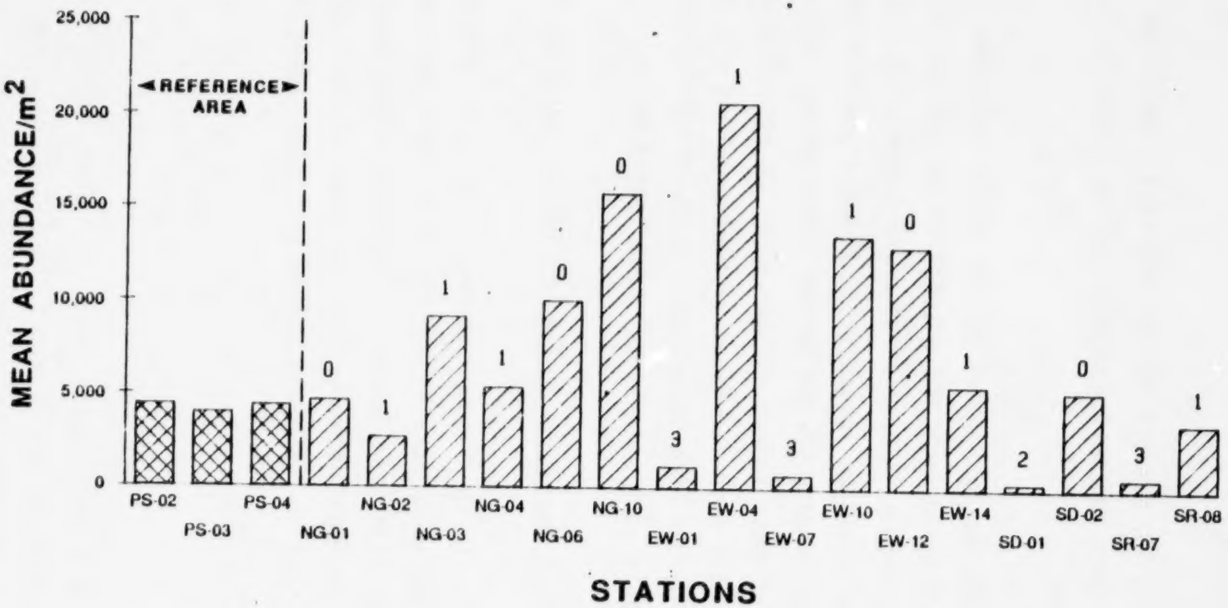
For these reasons, data on abundances of the major taxonomic groups at the three stations in Port Susan were not stratified by habitat characteristics prior to statistical testing. Stratification of between-station comparisons by sediment grain size would be inconsistent because grain-size characteristics cannot be matched in many of the paired comparisons. Instead, the data were pooled, such that mean values of variables at each station in Everett Harbor were compared with mean values of variables across all three stations in Port Susan. Pooling the Port Susan data increased the number of replicate reference values used in each statistical test from 5 to 15.

Comparisons of Benthic Communities in Everett Harbor and Port Susan

Nineteen benthic stations were sampled as part of the Everett Harbor study. Three stations were located in the Port Susan reference area, six stations were located along the South Port Gardner shoreline, six stations were located within the East Waterway, and two stations each were located in the Snohomish River and delta areas. Species-level identifications were available for all stations.

Infaunal Abundance--

A total of 62,419 individuals were collected among the 19 stations sampled in 1986. Abundances varied among the different areas, but tended to be higher in the East Waterway and in South Port Gardner. Total abundances at the station in Port Susan were very similar to each other and ranged from 3,950 to 4,418/m^2 ($\bar{x}$=4,249/m^2) (Figure 43). In contrast, total abundances



Note: Numbers at top of bars indicate numbers of significant depressions detected in major taxa abundances relative to the Port Susan reference area.

Figure 43. Mean number of individuals/m^2 at each benthic station in Everett Harbor and Port Susan.

at stations in Everett Harbor ranged from 300 to 20,676/m^2 ($\bar{x}$=7,005/m^2). Hence, total infaunal abundances at the stations in Everett Harbor were more variable than total abundances at the stations in Port Susan.

Abundances of the major taxonomic groups were also highly variable in Everett Harbor, compared with those in Port Susan (see Appendix F). Polychaete abundances ranged from 1,002 to 2,152/m^2 among the Port Susan stations, and from 10 to 14,462/m^2 among the Everett Harbor stations. Total crustacean abundances ranged from 650 to 1,344/m^2 among the Port Susan stations, and from 16 to 10,644/m^2 among the Everett Harbor stations. Abundances of other major taxonomic groups (i.e. gastropods, pelecypods, amphipods, other crustaceans, echinoderms and miscellaneous taxa) also showed similar high degrees of variability in Everett Harbor. Polychaetes followed by pelecypods, total crustaceans, and crustaceans other than amphipods were the most abundant major taxonomic groups in Port Susan, whereas total crustaceans followed by polychaetes, other crustaceans, and pelecypods were the most abundant major taxonomic groups among the Everett Harbor stations (see Appendix F). Gastropods and echinoderms were very minor contributors (i.e., <5.0 percent) to species richness and abundance at most stations.

Statistical analyses of infaunal abundances were conducted during this study to determine whether any of the differences in abundances (i.e., enhancements or depressions) between the Port Susan reference stations and stations in Everett Harbor were significant. Results of the t-tests are summarized in Table 26. The relative degree of impact at each test station was estimated by ranking stations according to the number of significant depressions in the abundances of the following major taxonomic groups: polychaetes, total crustaceans, pelecypods and gastropods. (For a discussion of the statistical rationale, see **Indices for Decision Criteria** below). Among the 64 paired comparisons that were performed (i.e., 16 stations times 4 major taxonomic groups), 28 comparisons were not statistically significant, 18 comparisons indicated enhanced abundances, and 18 indicated depressed abundances (Table 26). In comparisons with the reference area, polychaetes and pelecypods in Everett Harbor most frequently exhibited depressed abundances, whereas total Crustacea in Everett Harbor most often exhibited

TABLE 26. RESULTS OF PAIRWISE COMPARISON FOR ABUNDANCE OF MAJOR TAXA BETWEEN THE PORT SUSAN AND EVERETT HARBOR STATIONS[a]

Station	Total Abundance	Polychaetes[b]	Pelecypods[b]	Gastropods	Total Crustaceans[b]
NG-01	NS[c]	NS	NS	NS	NS
NG-02	-[d]	-	NS	NS	NS
NG-03	+[e]	-	+	+	+
NG-04	NS	-	+	+	+
NG-06	+	NS	+	+	+
NG-10	NS	+	+	+	+
EW-01	NS	-	-	-	NS
EW-04	+	+	-	NS	NS
EW-07	-	-	-	-	NS
EW-10	NS	+	-	NS	NS
EW-12	NS	NS	NS	+	+
EW-14	NS	NS	-	NS	NS
SD-01	-	-	-	NS	NS
SD-02	NS	NS	NS	NS	+
SR-07	-	-	-	NS	-
SR-08	NS	NS	-	NS	NS

[a] Significance level for a single comparison of either depressions or enhancements = $P \leq 0.001$.

[b] Used as index for decision criteria.

[c] NS = Not significant at $P \leq 0.001$.

[d] - = Abundance significantly depressed.

[e] + = Abundance significantly enhanced.

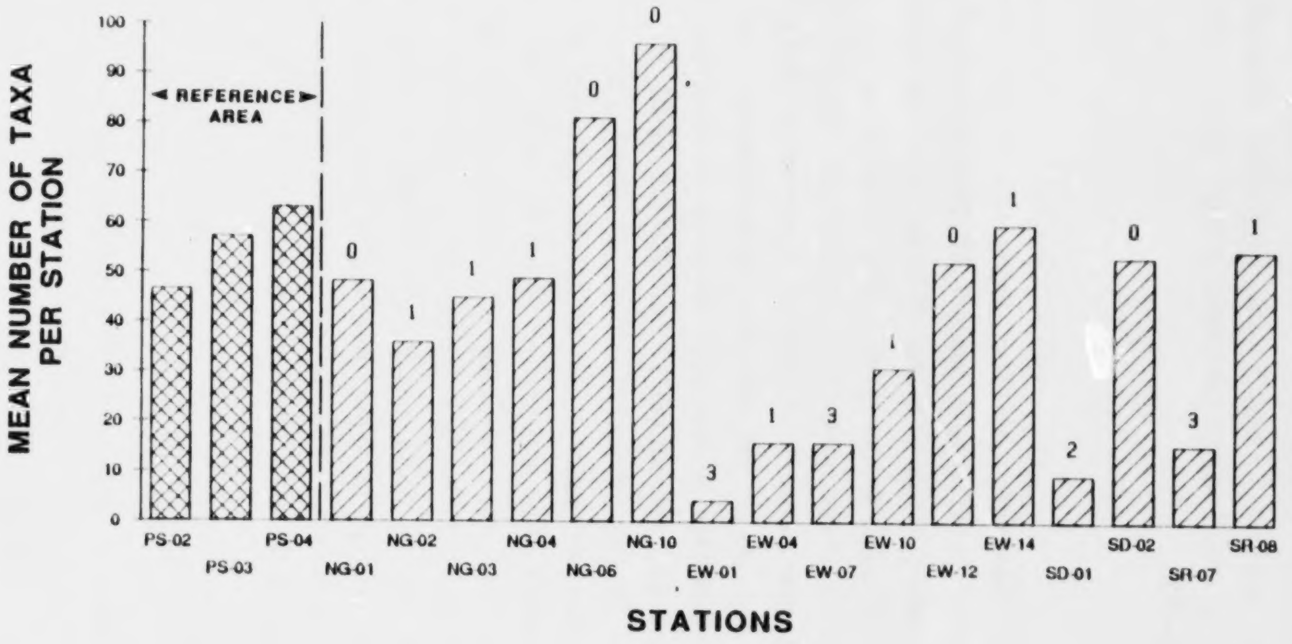
elevated abundances. Two stations in the East Waterway (i.e., EW-01 and EW-07), Station SD-01 near the mouth of Ebey Slough, and Station SR-07 in the Snohomish River exhibited the greatest number of depressions (two or three out of four) in abundances of the major taxonomic groups. Four stations in South Port Gardner exhibited significant ($P \leq 0.001$) elevations in the abundances of three or four major taxonomic groups (i.e., Stations NG-03, NG-04, NG-06, and NG-10).

Numbers of Taxa--

A total of 403 taxa were collected among the 19 stations sampled in Everett Harbor and Port Susan. Mean numbers of taxa per 0.1-m^2 grab sample varied considerably among those stations (Figure 44). At stations in Port Susan, mean numbers of species per grab varied from 47 to 63, and averaged 55.6. In Everett Harbor, mean numbers of species per station varied from 4 to 96. The highest mean numbers of species occurred in South Port Gardner at Stations NG-06 and NG-10 (96 and 81, respectively). The lowest mean numbers of species occurred in the East Waterway at Stations EW-01, EW-04 and EW-07 (4, 16 and 16, respectively), at Station SD-01 in the Snohomish River Delta (9) and in the Snohomish River at SR-07 (16). Two or three significant depressions of major taxa abundance occurred at each of the stations that exhibited low numbers of species, with the exception of Station EW-04 where only the abundance of pelecypods was depressed. The remaining nine stations in Everett Harbor (i.e., Stations NG-01, NG-02, NG-03, NG-04, EW-10, EW-12, EW-14, SD-02, and SR-08) exhibited mean numbers of species that were similar to those observed in Port Susan: 31-60 species per grab sample (Figure 44). One or no significant depressions in major taxa abundances occurred at each of these stations.

Numerically Abundant Taxa--

Relative and absolute abundances of the five numerically dominant taxa at each station are summarized in Appendix G. Among the Port Susan stations, abundances and relative abundances of the dominant taxa were fairly consistent. They ranged from 2,130 to 3,002/m^2 and from 53.9 to 67.9 percent of the fauna, respectively. Species composition of the dominant taxa among



Note: Numbers at top of bars indicate numbers of significant depressions detected in major taxa abundances relative to the Port Susan reference area.

Figure 44. Mean numbers of benthic taxa (no./0.1 m^2) at stations in Everett Harbor and Port Susan (1986).

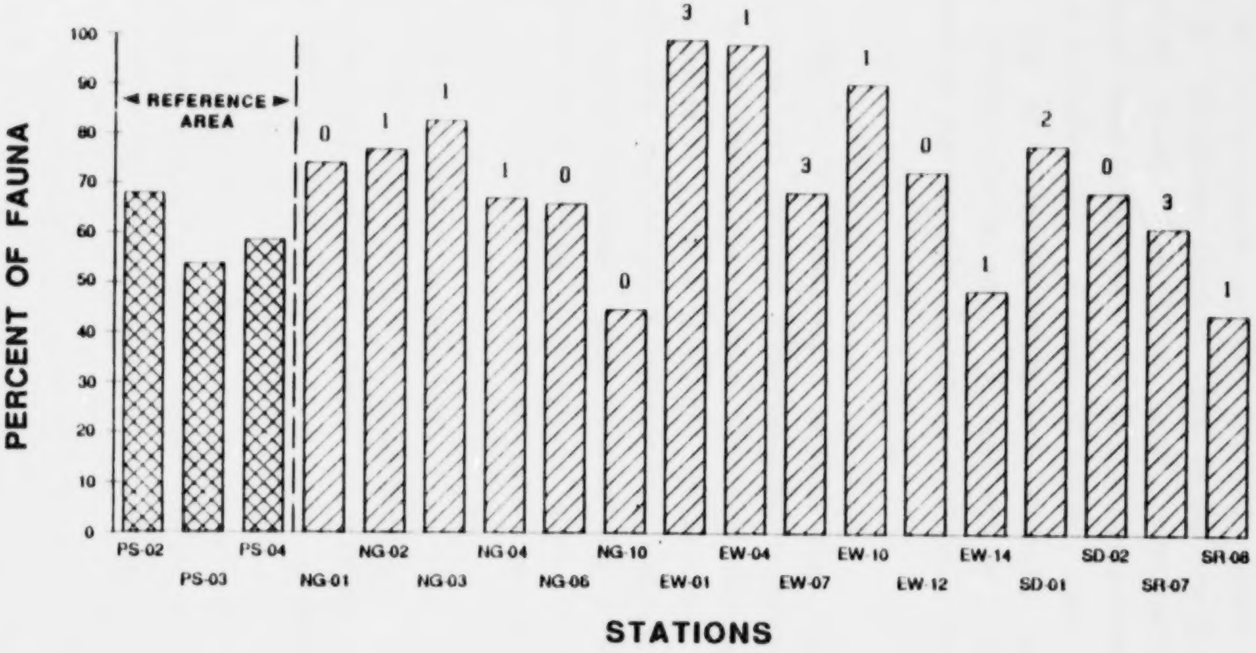
these stations was also similar. Each station had at least two, and as many as four taxa in common with each of the other stations. Moreover, at no station did a single taxon dominate the community to the exclusion or near exclusion of other taxa.

Among the Everett Harbor stations, relative abundances of the dominant taxa ranged from 44 to 99 percent of total infaunal abundances. At 8 of the 16 stations (i.e., Stations NG-01, NG-02, NG-03, EW-01, EW-04, EW-10, EW-12, and SD-01) the five numerically dominant taxa represented over 70 percent of the total abundance at each station (Figure 45). High relative abundances of dominant taxa often indicate stressed conditions. As less tolerant species are eliminated from the habitat, opportunistic species fill the vacant niches, often achieving high abundances (Pearson and Rosenberg 1978; Gray 1982).

Numerically dominant taxa averaged 2,567 individuals/m^2 among the Port Susan stations. Abundances of the numerically dominant taxa at most Everett Harbor stations were greater than this average, and abundances at Stations NG-03, NG-06, NG-10, EW-04, EW-10, and EW-12 greatly exceeded this value (Figure 45). These stations also exhibited significant enhancements for total infaunal abundance and several major taxonomic groups including pelecypods, gastropods, and total crustaceans. Abundances of amphipods (as a subgroup of crustaceans) were also enhanced significantly.

Abundances of the numerically dominant taxa were greatly depressed below the corresponding Port Susan value at Stations EW-01, EW-07, SD-01 and SR-07. Total abundance per station ranged from 300 to 1,162 individuals/m^2. Greatly depressed abundances often indicate excessively enriched sediments or the presence of toxic contaminants or both (see Pearson and Rosenberg 1978; Carriker et al. 1982; Wolfe et al. 1982; Dillon 1984; Bilyard 1987). These four stations exhibited the highest number of significant depressions among the Everett Harbor stations, with three or four depressions occurring at each station.

Swartz's Dominance Index (SDI) can be used as one indicator of stressed conditions due to organic enrichment. The index is defined as the number of



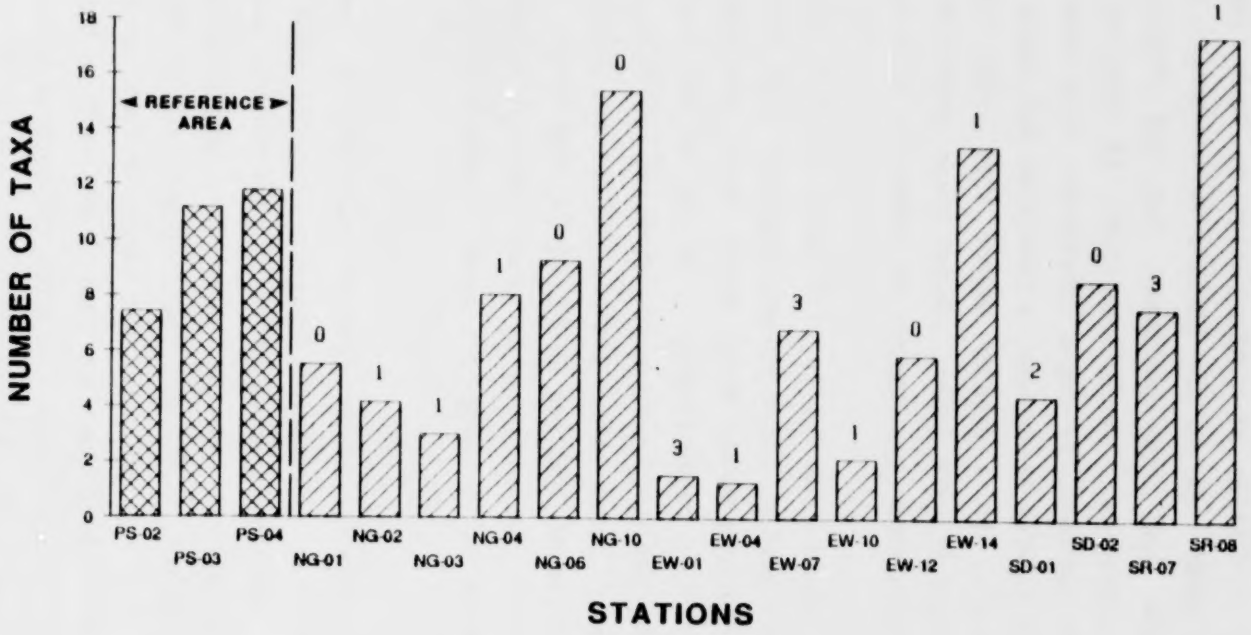
Note: Numbers at top of bars indicate numbers of significant depressions detected in major taxa abundances relative to the Port Susan reference area.

Figure 45. Relative abundances of the five numerically dominant taxa (as percent of total fauna) at stations in Everett Harbor and Port Susan (1986).

dominant taxa that account for 75 percent of the total abundance. A low index value results when a few taxa contribute most of the individuals in the assemblage. A high index value results from a highly diverse population wherein a limited number of taxa do not dominate the assemblage. SDI appears to be less indicative of contamination by toxic substances or physically stressed conditions in the benthic environment. Under those conditions, abundances are often depressed, but the diversity of the community is less disrupted. Under conditions of physical stress or contamination of the sediments by toxic substances, both common and rare species often exhibit reduced abundances, a condition that tends to maintain the species distribution to a greater degree than under conditions of organic enrichment (see Bilyard 1987). Under these conditions, a higher index value may be calculated, even though the community is stressed.

Values of SDI ranged from 7.4 to 11.8 among the Port Susan stations ($\bar{x}$=10.1). In Everett Harbor, index values suggested that moderate stress may be occurring at Stations NG-01, NG-02, NG-03, EW-12, and SD-01 (SDI=5.5, 4.2, 3.0, 5.9, and 4.4, respectively). Values of SDI indicated that Stations EW-01, EW-04, and EW-10 were highly stressed (SDI=1.5, 1.3, and 2.1 respectively). However, index values did not reflect the greatly depressed abundances that occurred at Stations EW-07, SD-01, and SR-07, and that may be indicative of toxic contamination or great physical stress. The SDI values for all Everett Harbor and Port Susan stations are summarized in Figure 46.

An analysis of species composition at each of the Everett Harbor stations provided further information regarding impacted areas. Taxonomic composition of the dominant species differed considerably within Everett Harbor (see Appendix G). For example, nematodes, *Capitella capitata*, and the crustacean *Nebalia* spp. were among the dominant taxa at the stations in East Waterway. No other station in Everett Harbor or Port Susan exhibited a similar group of numerically dominant taxa. Sub-surface deposit-feeding nematodes and capitellid polychaetes are known to reach very high abundances in organically enriched sediments, often to the exclusion of other taxa (Nichols 1977; Pearson and Rosenberg 1978; Van Es et al. 1980). *Nebalia* spp. are not considered classic indicators of organic pollution, yet they are



Note: Numbers at top of bars indicate numbers of significant depressions detected in major taxa abundances relative to the Port Susan reference area.

Figure 46. Values of Swartz's Dominance Index (expressed as number of taxa) at stations in Everett Harbor and Port Susan (1986).

found at high abundances at many East Waterway stations. Field observations made during other benthic surveys in central Puget Sound found that Nebalia spp. only achieves high abundances where wood chips or fibers contribute to composition of the sediment (Word, J.Q., 8 April 1988, personal communication). Field observations made during this study confirmed the association of Nebalia spp. with wood chips. Station SR-07 was dominated by Tharyx spp. and several species of capitellid polychaetes (Heteromastus filibranchus and Barantolla americana). Tharyx spp. is a surface deposit-feeding polychaete (Fauchald and Jumars 1979) that was numerically dominant in many of the benthic communities in contaminated areas of Elliott Bay and Commencement Bay, and may be indicative of stressed conditions (Tetra Tech 1985a). In summary, the identities of the dominant taxa and the low total abundances observed at Stations EW-01, EW-07, and SR-07 suggest that the sediments at these stations are highly organically enriched, contaminated with toxins, or both.

Total abundance was also depressed at Station SD-01, but two crustaceans contributed greatly to the total abundance (i.e., Archaeomysis grebnitzkii and Grandifoxus grandis). It is reasonable to assume that these two species of crustaceans are pollution-sensitive. Species closely related to each, are either known to be pollution-sensitive, or are used as test organisms in water and sediment toxicity bioassays tests. Thus, species composition of the numerically dominant taxa indicates that some effect other than organic enrichment or toxic contamination contributed to the low total abundance recorded at this station. Field observations suggest that swift currents may cause great physical stress at this station.

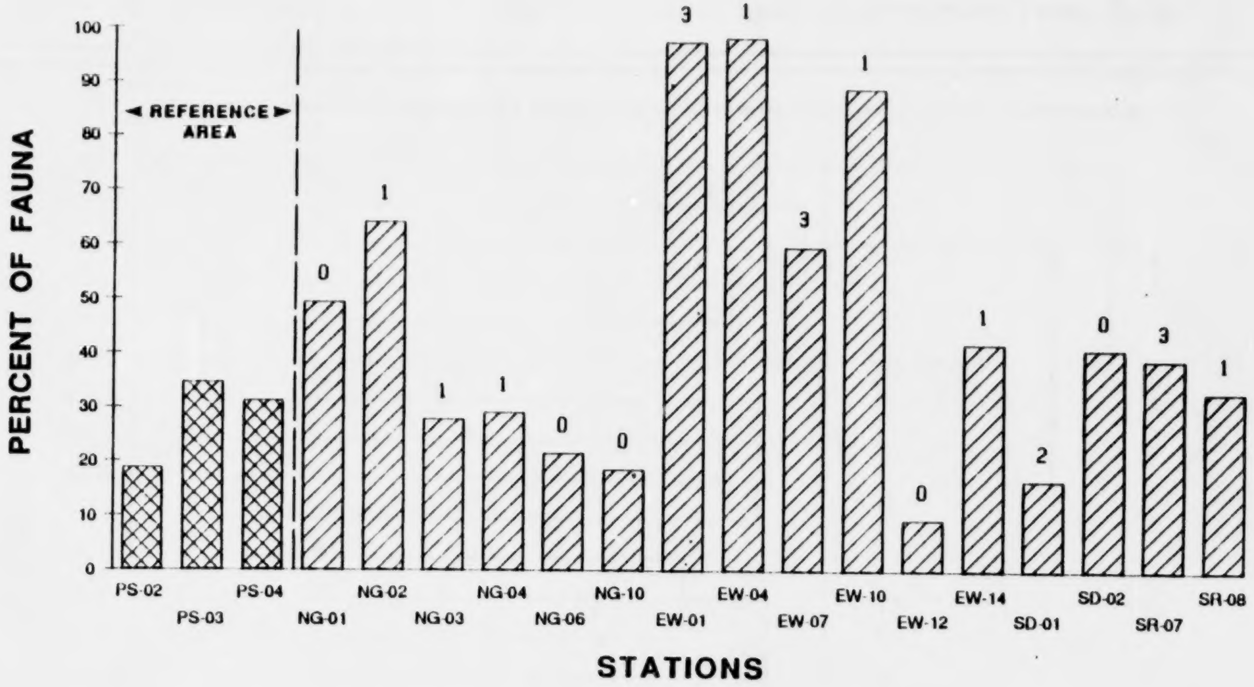
Relative abundances of opportunistic and pollution-tolerant taxa (as defined by Word et al. 1977; Pearson and Rosenberg 1978; Word 1980) at the 16 Everett Harbor stations and the three Port Susan stations further support the conclusion that benthic infaunal communities at many East Waterway and some other Everett Harbor stations are stressed. Among the Port Susan stations, relative abundances of opportunistic and pollution-tolerant taxa averaged 28.2 percent of the total fauna. The ostracods Euphilomedes carcharodonta and E. producta constituted the largest proportions of the opportunistic and pollution-tolerant taxa at these stations. Euphilomedes spp. are known to increase in abundance in areas where only slight to moderate organic enrichment of the ecosystem is occurring (Word et al. 1977). Within Everett Harbor, 9 of the 16 stations exhibited relative abundances of opportunistic and pollution-tolerant taxa that were higher than those at any of the Port Susan stations (Figure 47, see also Appendix H). Relative abundances of those taxa within Everett Harbor ranged from 40.8 to 98.2 percent of the total fauna. Stations EW-01, EW-04, and EW-10 exhibited the highest relative abundances of opportunistic and pollution-tolerant taxa, ranging from 88.9 to 98.2 percent. Two of these stations (i.e., Stations EW-01 and EW-07) also exhibited the greatest number of significant depressions in the abundances of the major taxonomic groups. Moreover, *Capitella capitata* contributed the largest proportion of opportunistic and pollution-tolerant taxa at all three stations. *C. capitata* is a known indicator of organically enriched conditions, and is often the only species found in highly stressed, organically enriched areas.

Relative abundances of opportunistic and pollution-tolerant species at Stations NG-03, NG-04, NG-06, NG-10 in South Port Gardner, EW-12 in the East Waterway, SD-01 and SR-08 in the Snohomish Delta and River ranged from 9.4 to 33.0 percent, and did not exceed the relative abundances of those taxa observed at the Port Susan stations. The most common opportunistic or pollution-tolerant species at these stations was *Euphilomedes carcharodonta*, which was also relatively abundant at the Port Susan stations.

Classification Analyses

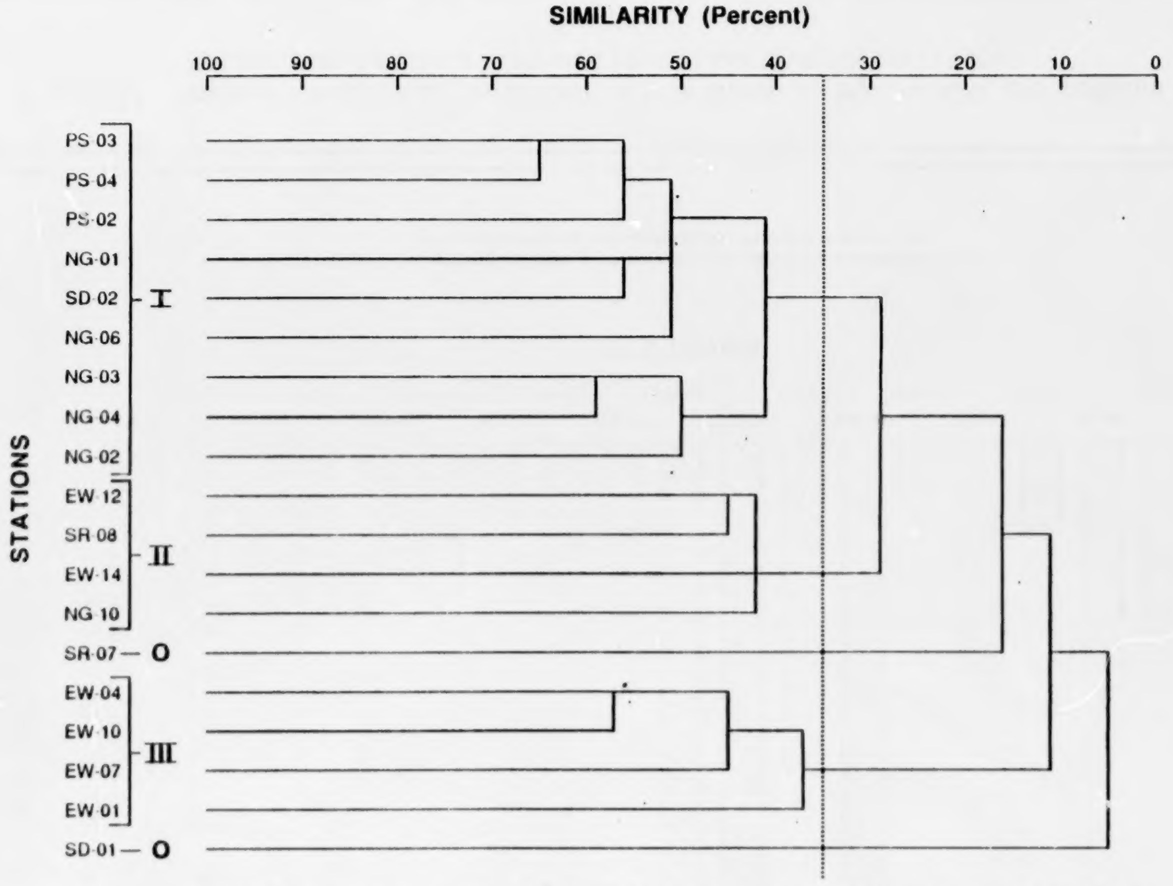
Similarities between station pairs and groups of stations based on the Bray-Curtis Similarity Index and normal classification analysis are shown in Figure 48. Station groups were determined by selecting a 35 percent similarity value. This level of similarity separated the stations into three interpretable groups with two outliers.

Group 1 included all three Port Susan stations, five South Port Gardner stations (i.e., Stations NG-01, NG-02, NG-03, NG-04 and NG-06), and one Snohomish River Delta station, Station SD-02. Results of the normal classification analysis indicated a high degree of similarity among the



Note: Numbers at top of bars indicate numbers of significant depressions detected in major taxa abundances relative to the Port Susan reference area.

Figure 47. Relative abundances (as percent of total fauna) of opportunistic and pollution tolerant taxa at stations in Everett Harbor and Port Susan (1986).



NOTE: Station groups delineated by a similarity level of 35 percent are enumerated. Outliers are designated as "O".

Figure 48. Results of a Q-mode classification analysis (Bray-Curtis similarity index, group average clustering strategy) using log-transformed [log(x+1)] abundances of the benthic infauna at stations in Everett Harbor and Port Susan (1986).

three Port Susan stations (56 percent). All other members of this group clustered at least 50 percent similarity. Stations PS-03 and PS-04 were very similar to one another, probably due to the similar abundances of Euphilomedes carcharodonta, Psephidia lordi, E. producta, and Pectinaria granulata that occurred at each station. These taxa were also among the five most abundant species at Port Susan stations. Euphilomedes carcharodonta and P. lordi were common to all nine stations in Group 1, and Axinopsida serricata, E. producta, and P. granulata were common to seven, four, and three of the stations, respectively. Sediments at the Port Susan stations in Group I ranged from coarse to fine sands. The five South Port Gardner stations in Group I and Station SD-02 exhibited a similar range of grain sizes as observed at the Port Susan stations. TOC content of the sediments was low among the Port Susan stations, ranging from 0.26 to 0.40 percent. Sediments at the remaining stations in this group exhibited TOC contents similar to those at the Port Susan stations (i.e., 0.18-0.54 percent). Among the Everett Harbor stations in this group, all exhibited either no significant depressions of major taxa abundance, or only one significant depression in the abundance of polychaetes (see Table 26).

Group 2 included Station NG-10 from South Port Gardner, Stations EW-12 EW-14 from the East Waterway, and Station SR-08. Between-station similarities ranged from 41 to 45 percent (based on the similarity coefficient). Fewer dominant taxa than Group 1 were common among the four stations. Alvania spp. and Platynereis bicanaliculata were both common at three stations, and Leptochelia dubia was common at two stations. The sediments at Stations EW-12 and SR-08 consisted primarily of medium to fine sands. Stations NG-10 and EW-14 also exhibited sandy substrate but sediments at those stations included 12 and 38 percent gravel or gravel sized particles (i.e., woodchips), respectively. Total organic carbon content of the sediments at the stations in Group 2 ranged from 0.71 to 4.66 percent. One or no depressions in the abundances of the major taxonomic groups were recorded at each station in this cluster. Both of the two recorded depressions were for pelecypods.

Group 3 consisted of Stations EW-01, EW-04, EW-07 and EW-10. All four stations were numerically dominated by Capitella capitata, nematodes and

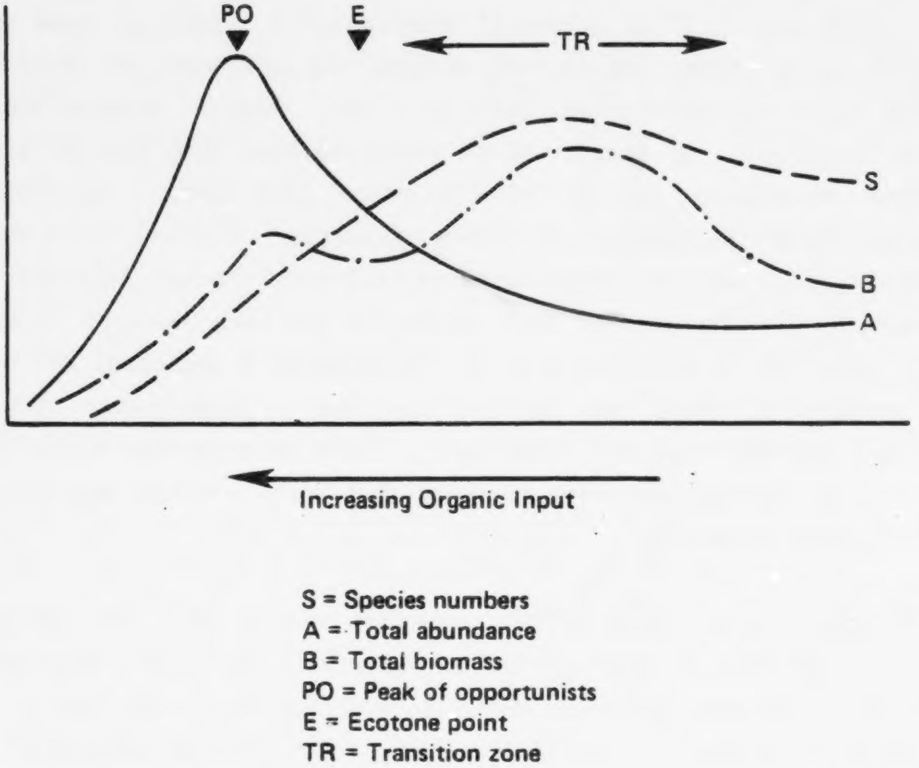
Nebalia spp. C. capitata and nematodes were the most abundant at Stations EW-04 and EW-10. These stations clustered together with a fairly high similarity coefficient (57 percent). Results of the t-tests documented significant enhancements in abundances of polychaetes at both stations. These same taxa were also dominant at Stations EW-01 and EW-07, but abundances there were very low. Abundances of polychaetes, pelecypods and gastropods were significantly depressed at Stations EW-01 and EW-07. Sediment characteristics were similar among all four stations. Percent fines (silt and clay) ranged from 56 to 79 percent. Most importantly, TOC content of the sediments was elevated at all four stations, and ranged from 8.7 to 29.4 percent. The highest TOC value occurred at Station EW-04, which also exhibited the highest total abundance (i.e., 20,676/m^2) among the Everett Harbor and Port Susan stations sampled in 1986.

Stations SD-01 and SR-07 were both outliers in the classification analysis. Low total abundances were recorded at both stations, and both exhibited significant depressions in the abundances of polychaetes and pelecypods. Total crustacean abundances were also depressed at Station SR-07. Archaeomysis grebnitzkii and Grandifoxus grandis were the most common species at Station SD-01. Species composition at this station was the least similar of all the Everett Harbor stations. The hydrographic regime at this station (i.e., high currents) probably contributed to this unique species composition. Station SR-07 was numerically dominated by Tharyx spp., Macoma nasuta, M. carlottensis, and Heteromastus filibranchus. These species are opportunistic or pollution-tolerant, and are often numerically dominant in areas where sediments are organically enriched, or where other stresses favor opportunistic species. The sediments at Station SD-01 were coarse sand with some gravel. Sediment TOC content was low (i.e., 0.24 percent) and comparable to that in Port Susan and at other Everett Harbor stations. The sediments at Station SR-07 were primarily clayey silts (percent fines = 95.4 percent). This sediment type was found at no other station in Everett Harbor. Sediment TOC content was 3.2 percent, a value slightly higher than most sediments throughout Puget Sound.

Comparison of Species and Major Taxa Level Analyses

Species-level data provided detailed information about benthic communities at each test station in Everett Harbor. In most cases, the species data identified the same problem areas as did the statistical comparisons using abundances of major taxonomic groups. Pairwise statistical comparisons of the abundances of major taxonomic groups identified Stations EW-01, EW-07, SD-01 and SR-07 as potential problem areas. Each of these stations exhibited three or four depressions in total abundances or the abundances of the four major taxonomic groups (see Table 26). However, examination of the species composition at Station SD-01 suggested that this station exhibited depressed abundances due to effects other than organic enrichment or contamination of the sediments by toxic substances. Although total abundance at Station SD-01 was the lowest observed in Everett Harbor, this station was dominated by two crustaceans that belong to families that are known to be highly sensitive to pollutants (i.e., phoxocephalid amphipods and mysids). Other members of these two families are used as experimental animals in water and sediment toxicity bioassays. Field observations suggested that this station experiences swift currents that cause extreme physical stress on the benthic community.

Further examination of benthic community indices that use species-level data indicated that in addition to Stations EW-01 and EW-07, Stations EW-04 and EW-10 in the East Waterway were also experiencing stress due to organic enrichment. The species composition at these two stations were very similar to those at Stations EW-01 and EW-07. All four of these stations were dominated by opportunistic or pollution-tolerant taxa (i.e., nematodes, _Capitella_ _capitata_, and _Nebalia_ spp.) The sediments at Stations EW-04 and EW-10 contained the highest concentrations of sulfides and total organic carbon measured at any Everett Harbor station. The benthic communities at these stations exhibit the classic response to high organic enrichment [as defined by Pearson and Rosenberg (1978)] wherein opportunistic species become very abundant and dominate the benthic community (Figure 49). Between station statistical comparisons of the abundances of the major taxonomic groups were unable to detect a potential problem at these stations because abundances of the numerically dominant taxa were extremely elevated. Only



Reference: Pearson & Rosenberg (1978).

Figure 49. Generalized diagram of changes in species, abundance, and biomass along a gradient of organic enrichment.

pelecypods exhibited significant depressions in abundance at these stations (see Table 26).

In general, crustaceans as a group did not display the sensitivity to pollutant stress that has been observed in other Puget Sound embayments. Examination of the species data suggested that this phenomena may have been due (in part) to the abundance of a group of amphipods (*Aoroides* spp.) that appear to be tolerant of, or enhanced by, organic enrichment. This group of amphipods was present at 13 of the 19 stations sampled in Everett Harbor and Port Susan and was among the dominant taxa at Stations EW-04, EW-07, EW-10 and EW-14. These four stations were characterized by fine-grained sediments (percent fines ranged from 32.3 to 77.1 percent), elevated sediment sulfide concentrations (700-7,610 ppm) and elevated sediment TOC content (4.7-29.4 percent). An additional dampening effect to the responsiveness of crustaceans to environmental contamination was created by the presence *Euphilomedes* spp. *Euphilomedes carcharodonta* was dominant at 11 of the 19 stations sampled and was often the most abundant taxon.

Indices for Decision Criteria

Concentrations of toxic substances in the sediments may cause reductions in the abundances of sensitive taxa (Wolfe et al. 1982; Rygg 1985, 1986) or all taxa (Bilyard 1987). An extreme degree of organic enrichment may also result in the loss of infaunal species (Pearson and Rosenberg 1978). In this study, the locations and magnitudes of impacts were determined by the results of the comparisons of major taxa abundance between Port Susan and Everett Harbor stations discussed earlier (see Table 26). Species level data were used to infer whether the presence of organic materials, toxic substances, or possibly other effects were causing the observed depressions in taxonomic abundance.

The relative degree of impact at each test station was estimated by ranking stations according to the number of statistically significant depressions in the abundances of Polychaeta, Crustacea, Pelecypoda, and Gastropoda. The major taxonomic groups comprise many different species with varying degree of sensitivities to organic enrichment and toxic chemicals.

In general, pelecypods and crustaceans appear to be fairly sensitive to stressed conditions, and tend to exhibit reduced abundances. Because of this sensitivity, they tend to be good indicators of stressed conditions at the major taxonomic level. In contrast, polychaetes tend to have species that are both sensitive and tolerant to these inputs. Because of this variability, polychaetes often provide less useful information at the major taxonomic level. Moreover, total infaunal abundance often mirrors polychaete abundance because polychaetes are often the most abundant group, and may account for greater than 50 percent of the total abundance.

The aforementioned pattern of sensitivity among the major taxonomic groups has been observed in several Puget Sound urban embayments, including Elliott Bay (PTI and Tetra Tech 1988) and Commencement Bay (Tetra Tech 1985a). However, in Everett Harbor the major taxonomic groups did not always exhibit typical responses. Hence, analyses of the abundances of the major taxonomic groups did not always provide complete indications of the factors to which the benthic communities were responding.

Using the statistically-detected differences in the abundances of the major taxonomic groups, Stations EW-01, EW-07, SD-01 and SR-07 appeared to be the most impacted: two or three depressions were recorded at each of these stations (Figure 50). Abundances of all major taxonomic groups at these four stations were depressed 70 to 100 percent when compared with abundances at Port Susan. East Waterway Stations EW-01 and EW-07 were dominated by nematodes and Capitella capitata, both of which are opportunistic or pollution-tolerant taxa. These stations may be responding to extreme organic enrichment, sediment contamination by toxic substances or both. It is difficult to attribute causality to these effects because high levels of organics in the sediments and toxic substances can cause large depressions in infaunal abundances. However, examination of the benthic communities at nearby Stations EW-04 and EW-10 showed extremely elevated populations of the same species. Sediments at these four East Waterway stations were characterized by fine grained sediments (percent fines ranged from 56.4 to 78.8), elevated levels of total organic carbon (6.0 to 29.4 percent), and very high concentrations of total sulfides (1,200 to 7,610 ppm). Based on these data it appears that these four stations were responding to organic enrichment

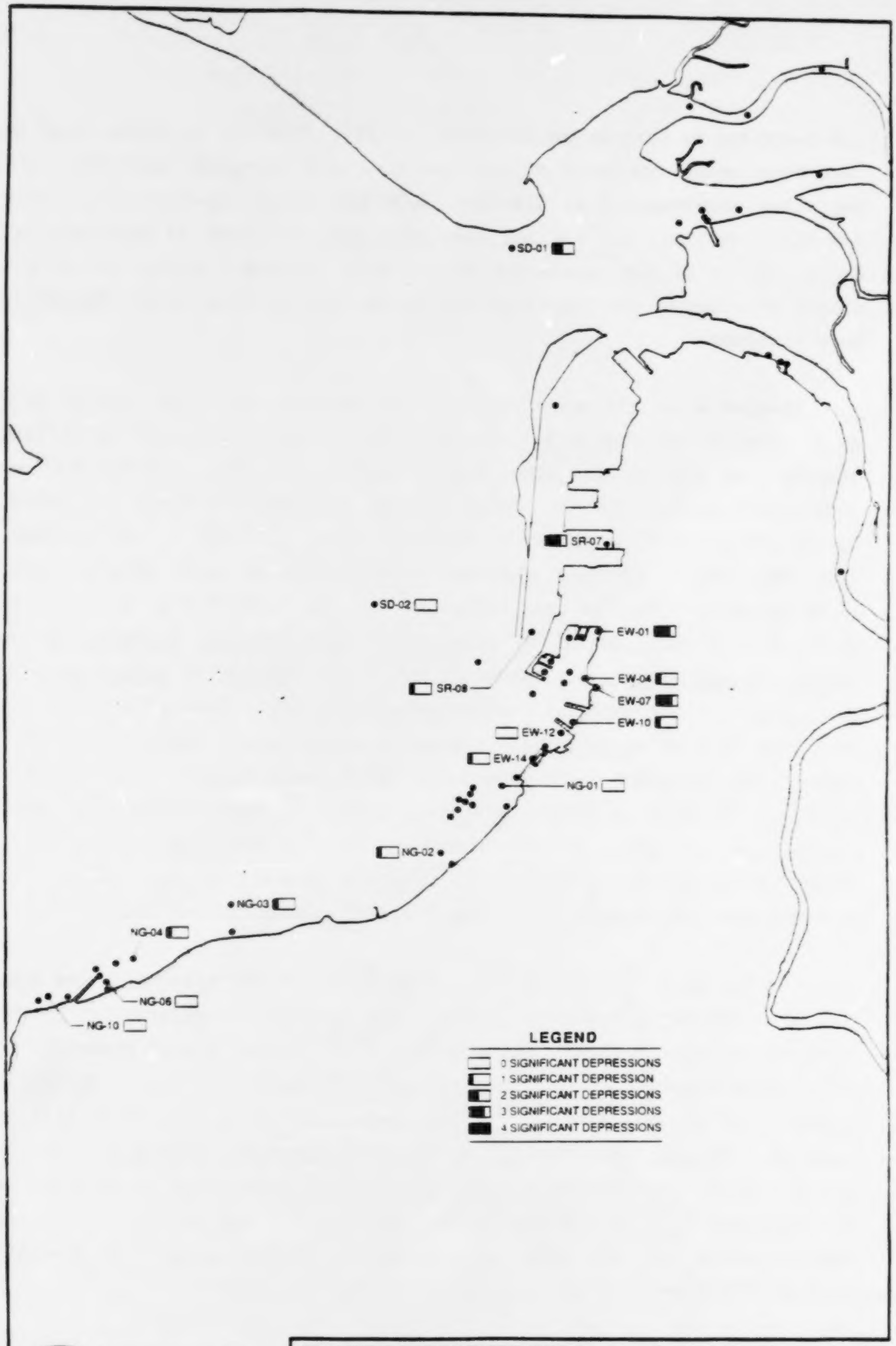

SD-01
SD-02
SR-07
SR-08
EW-01
EW-04
EW-07
EW-10
EW-12
EW-14
NG-01
NG-02
NG-03
NG-04
NG-06
NG-10
LEGEND
0 SIGNIFICANT DEPRESSIONS
1 SIGNIFICANT DEPRESSION
2 SIGNIFICANT DEPRESSIONS
3 SIGNIFICANT DEPRESSIONS
4 SIGNIFICANT DEPRESSIONS
0
5000
feet
meters
0
1500

Figure 50. Summary of spatial patterns of significant ($P \leq 0.001$) benthic depressions among the Everett Harbor stations

[as described by Pearson and Rosenberg (1978)]. Stations EW-01 and EW-07 may have been beyond the "peak of opportunists," and therefore exhibited highly depressed abundances. At Stations EW-04 and EW-10, opportunistic species are still dominant but may not have gone past the "peak of opportunists." Exclusive use of the abundances of the major taxonomic groups was able to detect only two of the four stations in the East Waterway where communities were stressed.

Abundances of the major taxonomic groups also identified Station SR-07 as a potential problem site. Species composition at this station differed greatly from that at most other Everett Harbor stations. Station SR-07 was also characterized by the finest-grained sediments observed in Everett Harbor (fines = 95.4 percent), elevated total sulfides in the sediments (600 ppm), and a slightly elevated concentration of total organic carbon (3.24 percent). Species data indicated that the community at this site was dominated by two capitellid polychaetes (Heteromastus filibranchus and Barantolla americana), two species of the bivalve Macoma (M. carlottensis and M. nasuta) and the cirratulid polychaete Tharyx spp. Several of these taxa have been defined as pollution-tolerant or opportunistic (Word et al. 1977; Pearson and Rosenberg 1978; Word 1980) which would support the interpretation that the benthic community at this station is experiencing some degree of pollutant stress. However, data are insufficient (i.e., there are no other nearby benthic stations) to interpret whether or not the observed stresses are due to organic enrichment, toxic substances, or both.

Station SD-01 also exhibited a high number of depressions in the abundances of the major taxonomic groups. The physical characteristics of this station consisted of sandy sediments (with 12 percent gravel present), low total organic carbon content, low sulfide, and swift currents. The species composition at this station was the least similar to all other stations sampled. It was dominated by the mysid Archaeomysis grebnitzkii and the phoxocephalid amphipod Grandifoxus grandis. A few pollution-tolerant or opportunistic taxa were present (16.7 percent). These data contradict the identification of this site as a potential problem area. As discussed earlier this community may be stressed by physical factors.

No other station in Everett Harbor was identified as a potential problem area using depressed abundances of the major taxonomic groups as the decision criteria. All other stations (i.e., Stations NG-01, NG-02, NG-03, NG-04, NG-06, NG-10, EW-12, EW-14, SD-02 and SR-08) exhibited only one or no depressions. Sediment characteristics (i.e., grain size, TOC, sulfides) at the majority of these remaining stations were very similar to Port Susan sediments. Species composition at each of these stations was also very similar to Port Susan, with Euphilomedes carcharodonta, Axinopsida serricata, and Psephidia lordi being the dominant taxa at 50-80 percent of these remaining stations.

Comparison with Recent Historical Data

Historical data collected during 1984 and 1985 during the Navy Homeport Study (Parametrix 1985; U.S. Army COE 1985) were reviewed and compared with the results of this study. In 1984, nine stations were sampled in the nearshore areas of Everett Harbor, the East Waterway and the Snohomish River. This study was conducted in the summer of 1984, and the majority of the stations were located in East Waterway. The 1985 study occurred in the winter and sampled seven stations located adjacent to the East Waterway, and in the lower Snohomish River and delta. The laboratory processing methods used in this later study were not comparable to standard benthic sample processing techniques (e.g. use of 1.0-mm screen) and tended to underestimate species richness and abundance of the benthic assemblages.

Historical data tended to identify problem areas similar to those found in this study. Total abundances at the historical stations sampled in the East Waterway ranged from 52 to 5,203 individuals per station and mean number of taxa collected there ranged from 1.8 to 21.4. The benthic community was dominated by Capitella capitata, nematodes, and Nebalia pugettensis. In some areas within the East Waterway in 1984, these species accounted for 100 percent of the organisms collected. SDI calculated for these stations reflected these highly dominated assemblages: most values were less than 1.0. Reference areas were not sampled as part of these historical studies so no statistical comparisons of the abundances of the major taxonomic groups could be made. However, examination of the data showed that molluscs, total Crustacea, and amphipods were either absent, or occurred at very low abundances at many of these stations.

Additional historical stations adjacent to the mouth of East Waterway were also sampled during the 1984 and 1985 studies. Mean numbers of taxa at those stations ranged from 31.6 to 69 per station. Total abundance was also higher at those stations than at stations in the East Waterway, and ranged from 2,496 to 9,676 individuals/m^2. SDI was less than 5.0 at all stations. Communities were dominated by many of the same taxa as in East Waterway, but included *Euphilomedes carcharodonta*.

Values of various benthic community indices that were calculated using historical data from the three stations in the Snohcmish River initially suggested a potential problem in the lower river where the channelization of the river mouth begins. Numbers of taxa and total abundances were low at two stations (mean nos. of taxa were 7 and 7; total abundances were 265 and 556), and values of SDI were low (1.80 and 2.85). However, the numerically dominant taxa at these stations were not indicative of a high degree of stress related to organic enrichment or the presence of toxic substances in the sediments. Insufficient data are available to determine whether the benthic community in this area was responding to some type of physical stress.

Numbers of taxa and total abundances recorded at three historical stations sampled within the river delta were slightly higher than in samples from the river channel. Mean numbers of taxa ranged from 13.8 to 20 per station, and total abundance ranged from 374 to 1,299 individuals/m^2. Values of SDI ranged from 3.44 to 4.17. In most cases, these values of the SDI would suggest that the possibility of stresses to the benthic community be explored.

Summary

- Eighteen significant ($P \leq 0.001$) depressions in abundances were detected among 64 statistical comparisons of four major taxonomic groups at 16 benthic stations in Everett Harbor.

Significantly enhanced abundances were detected in 18 cases, and no significant differences were found in 28 comparisons.

- Five stations in Everett Harbor exhibited no depressions in the abundances of the four major taxa selected for problem identification (polychaetes, pelecypods, gastropods and total crustaceans). Seven stations exhibited one depression, one station exhibited two depressions, and three stations exhibited three depressions.

- The most impacted stations in Everett Harbor were Stations EW-01, EW-07 (East Waterway), SD-01 (Snohomish River Delta), and SR-07 (Snohomish River) based on depressions detected in major taxonomic abundance. Species level data also identified East Waterway Stations EW-04 and EW-10 as being greatly impacted.

- The lowest number of taxa occurred at Stations EW-01, EW-04, EW-07, SD-01, and SR-07, all of which exhibited three significant ($P \leq 0.001$) depressions in the abundances of the major taxonomic groups, with the exception of Station SD-01, where polychaetes and pelecypods were depressed, and Station EW-04, where only pelecypods were depressed. Station EW-04 was also characterized by the highest total abundance of benthic infauna observed in Everett Harbor in 1986.

- Species compositions of the benthic communities at the East Waterway stations was very similar. Several dominant taxa were common to those stations. This area had the greatest number of stations that exhibited significant depressions in abundances of the major taxonomic groups. Many of the numerically dominant taxa present at the South Port Gardner Stations SD-02 and SR-08 were also numerically dominant in Port Susan. Only one group or no groups exhibited depressed abundances at Stations SD-02, SR-08, or any of the stations in South Port Gardner.

- Station groups that resulted from the classification analysis tended to confirm the identification of potential problem areas based on both the depressed abundances of the major taxonomic groups and on species composition. Stations EW-01, EW-04, EW-07, and EW-10 were included in one group, Stations EW-12, EW-14, NG-10, and SR-08 were included in a second group, Stations PS-02, PS-03, PS-04, NG-01, NG-02, NG-03, NG-04, NG-06, and SD-02 were included in a third group, and Stations SR-07 and SD-01 were outliers.

FISH ECOLOGY

This section provides a description of the general characteristics of the demersal fish assemblages and English sole populations sampled at the 10 transects in Everett Harbor and the single transect in Port Susan (see Figure 6). Demersal fish assemblages are compared between Everett Harbor and Port Susan with respect to species composition, total abundance, total number of species, and diversity. English sole populations are compared between the two areas with respect to abundance and relative abundance.

Demersal Fish Assemblages

Species Composition--

A total of 6,373 fishes, representing 17 families and 38 species, was sampled in this study (Table 27). Everett Harbor yielded 5,790 individuals and 37 species, whereas 583 individuals and 21 species were captured at Port Susan. Much of the observed difference in catches between the two study areas likely resulted from the larger sampling effort expended in Everett Harbor, but may also have been partly the result of increased habitat complexity (e.g., pilings, rocks, debris) in Everett Harbor.

The most abundant family of fishes sampled in both Everett Harbor and Port Susan was Pleuronectidae (62.6 and 48.3 percent, respectively). The

TABLE 27. RELATIVE ABUNDANCES OF FISHES CAPTURED IN EVERETT HARBOR AND PORT SUSAN

Family	Species	Common Name	Relative Abundance (%) Everett Harbor	Relative Abundance (%) Port Susan
Squalidae	*Squalus acanthias*	spiny dogfish	<0.1	0.3
Chimeridae	*Hydrolagus colliei*	ratfish	<0.1	
Clupeidae	*Clupea harengus pallasi*	Pacific herring	0.8	0.5
Osmeridae	*Hypomesus pretiosus pretiosus*	surf smelt	0.2	3.1
Batrachoididae	*Porichthys notatus*	plainfin midshipman	0.4	0.5
Gadidae	*Gadus macrocephalus*	Pacific cod	0.3	
	Theragra chalcogramma	walleye pollock		0.2
	Microgadus proximus	Pacific tomcod	16.9	24.5
Zoarcidae	*Lycodopsis pacifica*	blackbelly eelpout	1.3	1.5
Gasterosteidae	*Aulorhynchus flavidus*	tube-snout	0.1	
Embiotocidae	*Cymatogaster aggregata*	shiner perch	2.0	1.5
	Embiotoca lateralis	striped seaperch	0.2	
	Rhacochilus vacca	pile perch	2.8	0.3
Bathymasteridae	*Ronquilus jordani*	northern ronquil	<0.1	0.3
Stichaeidae	*Lumpenus sagitta*	snake prickleback	5.3	11.7
Scorpaenidae	*Sebastes caurinus*	copper rockfish	2.9	3.1
Hexagrammidae	*Hexagrammos decagrammus*	kelp greenling	<0.1	
	Hexagrammos stelleri	whitespotted greenling	<0.1	
	Oxylebius pictus	painted greenling	<0.1	
Cottidae	*Chitonotus pugetensis*	roughback sculpin	0.1	
	Enophrys bison	buffalo sculpin	0.2	0.5
	Leptocottus armatus	Pacific staghorn sculpin	0.4	0.5
	Myoxocephalus polyacanthocephalus	great sculpin	<0.1	
	Nautichthys oculofasciatus	sailfin sculpin	<0.1	
	Rhamphocottus richardsoni	grunt sculpin	<0.1	
	Scorpaenichthys marmoratus	cabezon	<0.1	
Agonidae	*Agonus acipenserinus*	sturgeon poacher	<0.1	0.7
Bothidae	*Citharichthys sordidus*	Pacific sanddab	<0.1	
	Citharichthys stigmaeus	speckled sanddab	2.9	2.2
Pleuronectidae	*Atheresthes stomias*	arrowtooth flounder	<0.1	
	Glyptocephalus zachirus	rex sole	0.3	
	Hippoglossoides elassodon	flathead sole	0.4	0.5
	Lepidopsetta bilineata	rock sole	7.3	3.4
	Lyopsetta exilis	slender sole	1.2	5.3
	Microstomus pacificus	Dover sole	0.8	
	Parophrys vetulus	English sole	52.1	37.9
	Platichthys stellatus	starry flounder	0.3	1.2
	Psettichthys melanostictus	sand sole	0.2	
		Total Catch	5,790	583

most abundant pleuronectid in both areas was English sole (52.1 and 37.9 percent, respectively).

Assemblage Characteristics--

Demersal fish assemblages at individual transects in Everett Harbor were compared qualitatively with the assemblage at Port Susan on the basis of three major characteristics: total abundance, total number of species, and diversity (Table 28). The latter variable was estimated using the Shannon-Wiener index (H') (Shannon and Weaver 1949).

Total abundance at 3 of the 10 Everett Harbor transects (i.e., EW-91, SD-92, SD-94) exceeded the value at Port Susan (i.e., 16.2 individuals/100 m) by a factor of 2 or greater. By contrast, total abundances at four Everett Harbor transects (i.e., NG-91, NG-92, NG-93, NG-94) were lower than the value at Port Susan by a factor of 2 or greater.

The total number of species at Everett Harbor transects (i.e., range = 11-24) exceeded the value observed at Port Susan (i.e., 21) at one transect (i.e., EW-92) and was lower than that value at the remaining nine transects. The diversity at Everett Harbor transects (i.e., range = 1.06-2.12) exceeded the value observed at Port Susan (i.e., 1.98) at one transect (i.e., EW-92) and was lower than that value at the remaining transects.

In summary, the total abundance of fish assemblages was substantially reduced along most of the southern shoreline of Port Gardner relative to the observed abundance in Port Susan. By contrast, total abundance of fish assemblages was much higher in the East Waterway and throughout most of the Snohomish Delta than the observed value in Port Susan. Throughout most of the Everett Harbor study area, both the number of species and diversity of fish assemblages were lower than the observed value in Port Susan. The only exception to this pattern was found at the transect outside of the East Waterway (i.e., EW-92). Although these comparisons are largely descriptive, the general pattern of reduced numbers of species and diversity values throughout most of the Everett Harbor study area suggest that fish assemblages may be negatively affected relative to the assemblage in Port Susan.

TABLE 28. COMPARISONS OF MAJOR CHARACTERISTICS OF FISH ASSEMBLAGES IN EVERETT HARBOR AND PORT SUSAN

Transect	Total Abundance (per 100 m)	Number of Species	Diversity (H')
Port Susan			
PS-91	16.2	21	1.98
Everett Harbor			
NG-93	6.3	17	1.77
NG-92	5.6	11	1.20
NG-91	5.4	11	1.43
NG-94	2.0	15	1.40
EW-92	15.5	24	2.12
EW-91	34.0	20	1.59
SR-92	12.6	17	1.06
SD-91	20.2	18	1.43
SD-94	39.8	13	1.06
SD-92	67.9	17	1.75

However, the reasons for these potential negative effects are uncertain. They could be related to chemical contamination or to other variables such as low salinity, low habitat complexity, or reduced densities of prey organisms.

English Sole Populations

The abundance of English sole at 3 of the 10 Everett Harbor transects (i.e., EW-91, SD-91, SD-92) exceeded that at Port Susan (i.e., 6.1 individuals/100 m) by a factor of 2 or greater (Table 29). By contrast, the abundance of English sole at three transects (NG-91, NG-93, NG-94) was lower than the value in Port Susan by a factor of 2 or greater. The relative abundance of English sole at Everett Harbor transects (i.e., range = 25.8-63.5 percent) exceeded the value observed at Port Susan (i.e., 37.9 percent) at all transects except Transect SD-94.

Summary

- The most abundant family of fishes in both Everett Harbor and Port Susan was Pleuronectidae

- The most abundant pleuronectid in both study areas was English sole

- The abundances of demersal fishes at four Everett Harbor transects were substantially lower (i.e., <50 percent) than the abundance at Port Susan

- The total numbers of species and diversities of fish assemblages at most transects in Everett Harbor were lower than the respective values at Port Susan.

FISH HISTOPATHOLOGY

This section presents the results of histopathological analyses conducted on the livers of English sole collected at 10 trawl transects in

TABLE 29. COMPARISONS OF ABUNDANCE AND RELATIVE ABUNDANCE OF ENGLISH SOLE IN EVERETT HARBOR AND PORT SUSAN

Transect	Abundance (per 100 m)	Relative Abundance (percent)
Port Susan		
PS-91	6.1	37.7
Everett Harbor		
NG-93	3.0	47.6
NG-92	3.5	62.5
NG-91	3.0	55.6
NG-94	1.3	65.0
EW-92	6.6	42.6
EW-91	20.1	59.1
SR-92	8.3	65.9
SD-91	12.8	63.4
SD-94	10.3	25.9
SD-92	27.3	40.2

Everett Harbor and at one transect in a reference area in Port Susan (see Figure 6). Three major kinds of lesion were evaluated: neoplasms, foci of cellular alteration, and megalocytic hepatosis (see **Methods** section). Before the lesions are considered, the age and sex characteristics of the English sole sample from each Everett Harbor transect are compared with the respective characteristics of the sample from Port Susan. The overall prevalences of the lesions in Everett Harbor and at Port Susan are then presented, and the relationships between the prevalence of each lesion and fish sex and age are determined. Next, comparisons of lesion prevalences between each Everett Harbor transect and Port Susan are made. Finally, results of the present study are compared with historical information on the prevalence of hepatic lesions in English sole from Everett Harbor.

Age and Sex Characteristics of Fish Populations

Ages of English sole at three transects in Everett Harbor differed significantly ($P \leq 0.05$) from ages of fish captured in Port Susan (Table 30). In two cases (i.e., Transects NG-91 and NG-92), median fish age was greater than that observed in Port Susan. At Transect SR-92, median fish age was less than that observed in Port Susan. Male proportion of English sole at two transects in Everett Harbor (i.e., Transects NG-93 and EW-92) was significantly ($P \leq 0.05$) greater than the proportion in Port Susan (Table 30).

General Patterns of Lesion Prevalences

A total of 71 of the 594 (12.0 percent) English sole (age ≥3 yr) sampled from Everett Harbor and Port Susan had one or more of the three kinds of hepatic lesions considered in this study (Table 31). Of this total, 56 (9.4 percent) had only a single kind of lesion, 13 (2.2 percent) had two kinds of lesions, and 2 (0.3 percent) had all three kinds of lesions.

The prevalence of each kind of hepatic lesion evaluated in this study was greater in Everett Harbor than in Port Susan (Table 31). In most cases, the differences between these two areas were substantial. Foci of cellular alteration was the lesion found most frequently in Everett Harbor and Port

TABLE 30. COMPARISONS OF AGE AND MALE PROPORTION BETWEEN ENGLISH SOLE FROM EVERETT HARBOR AND PORT SUSAN

Transect	Sample Size[a]	Median Age (yr)[b]	Male Proportion[c]
Port Susan			
PS-91	56	4.0	0.18
Everett Harbor			
NG-93	56	4.4 ns	0.45*
NG-92	60	5.6***	0.08 ns
NG-91	58	5.7***	0.10 ns
NG-94	57	4.6 ns	0.18 ns
EW-92	55	3.6 ns	0.47*
EW-91	49	3.3 ns	0.41 ns
SR-92	41	3.0*	0.44 ns
SD-91	58	3.8 ns	0.28 ns
SD-94	51	3.8 ns	0.20 ns
SD-92	53	3.1 ns	0.17 ns

[a] All fish were ≥ 3 years old.

[b] Comparisons were made using the Mann-Whitney _U_-test. * = $P \leq 0.05$; *** = $P \leq 0.001$; ns = $P > 0.05$.

[c] Comparisons were made using the _G_-test of independence. * = $P \leq 0.05$; ns = $P > 0.05$.

TABLE 31. PREVALENCES OF HEPATIC LESIONS IN ENGLISH SOLE FROM EVERETT HARBOR AND PORT SUSAN

Hepatic Lesion	Everett Harbor (n=538[a])	Port Susan (n=56[a])
Neoplasms		
Liver cell adenoma	1.9	0
Hepatocellular carcinoma	0.7	0
One or more kinds of neoplasm[b]	2.4	0
Foci of celluar alteration		
Eosinophilic foci	7.6	5.4
Basophilic foci	3.0	0
Clear cell foci	2.2	1.8
One or more kinds of foci of cellular alteration[b]	10.8	7.1
Megalocytic hepatosis	2.4	0
One or more of the three major kinds of hepatic lesion[b]	12.5	7.1

[a] All fish were ≥3 years old.

[b] Some fish had more than one kind of hepatic lesion.

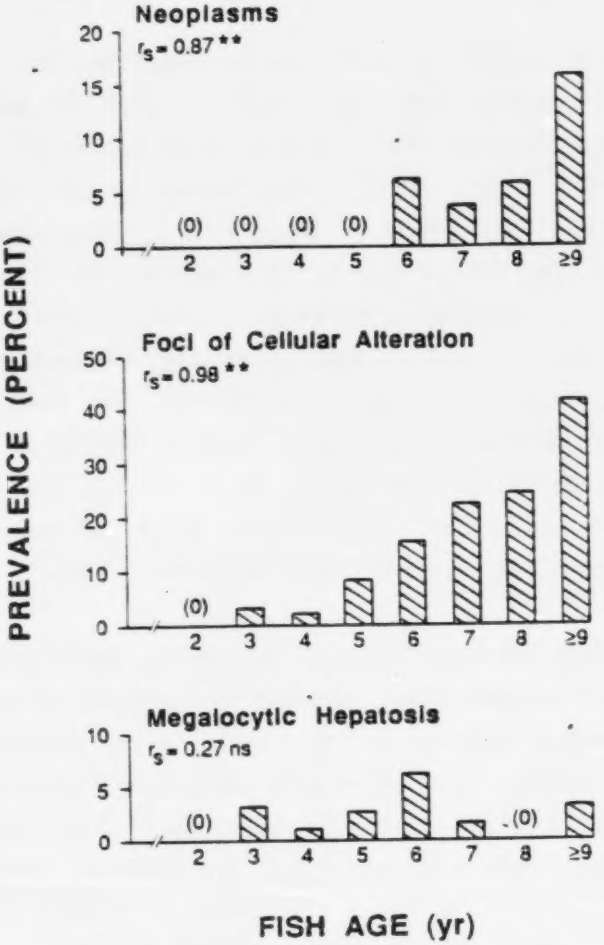
Susan (10.8 and 7.1 percent, respectively). Neoplasms and megalocytic hepatosis were not found in Port Susan.

Within Everett Harbor, prevalences of neoplasms and foci of cellular alteration were correlated positively ($P \leq 0.05$) with increasing age of fish (Figure 51). These patterns are consistent with the results of past studies (Malins et al. 1982; McCain et al. 1982; Becker et al. 1987; Rhodes et al. 1987; PTI and Tetra Tech 1988). Prevalence of neoplasms increased from 0 percent in fish aged 2-5 yr old to 15.6 percent in fish aged ≥9 yr old. Prevalence of foci of cellular alteration increased from 0 percent in 2-yr-old fish to 40.6 percent in fish aged ≥9 yr old. Prevalence of megalocytic hepatosis was not linearly correlated with fish age ($P > 0.05$) (Figure 51), which is consistent with results of past studies (Becker et al. 1987; Rhodes et al. 1987; PTI and Tetra Tech 1988). However, the prevalence of megalocytic hepatosis peaked at an age of 6 yr, which corresponds to the trend found by Tetra Tech (1985a) and PTI and Tetra Tech (1988).

The prevalence of megalocytic hepatosis exhibited a significant difference ($P \leq 0.05$) between sexes, whereas prevalences of neoplasms and foci of cellular alteration did not differ significantly ($P > 0.05$) between sexes (Table 32). Past studies of English sole populations have reported the lack of a difference in the prevalence of megalocytic hepatosis between sexes (McCain et al. 1982; Malins et al. 1982; Krahn et al. 1986; Becker et al. 1987; Rhodes et al. 1987).

Comparisons of Lesion Prevalences Between Study Areas

Because prevalences of neoplasms and foci of cellular alteration in Everett Harbor correlated with fish age (Figure 51), age distributions at those transects that differed from Port Susan with respect to fish age (i.e., NG-91, NG-92, and SR-92; Table 30) were adjusted before comparisons with the reference area were made. Adjustments were made by sequentially removing the youngest fish from Transect SR-92 and the oldest fish from Transects NG-91 and NG-92 until each remaining age distribution did not differ significantly ($P > 0.05$) from the age distribution at Port Susan. In making these adjustments, 4, 12, and 15 fish were removed from Transects



AGE GROUP	SAMPLE SIZE
2	62
3	137
4	128
5	78
6	65
7	60
8	38
≥9	32

Figure 51. Comparisons of prevalences of hepatic lesions with age of English sole from Everett Harbor using Spearman's coefficient of rank correlation (r_s). ** $P \leq 0.01$, ns = $P > 0.05$.

TABLE 32. COMPARISONS OF LESION PREVALENCES BETWEEN MALE AND FEMALE ENGLISH SOLE FROM EVERETT HARBOR

Hepatic Lesion	Percent having Each Kind of Lesion[a] Males (n=145)	Females (n=393)	Significance[b]
Neoplasms	2.8	2.3	ns
Foci of cellular alteration	11.0	10.7	ns
Megalocytic hepatosis	5.5	1.3	**

[a] All fish were ≥ 3 years old.

[b] Comparisons were made using the _G_-test of independence. ** = $P \leq 0.01$; ns = $P > 0.05$.

SR-92, NG-91, and NG-92, respectively. A graphical comparison between the age distribution at each Everett Harbor transect (including the three adjusted distributions) and the age distribution at Port Susan is presented in Figure 52.

Although prevalence of megalocytic hepatosis differed between sexes (Table 32), the sex distributions at those transects that differed from Port Susan with respect to male proportion were not adjusted before comparisons with the reference area were made. Adjustments were not made primarily because the relationship observed in this study is not consistent with results of past studies of hepatic lesions in English sole (McCain et al. 1982; Malins et al. 1982; Becker et al. 1987; Rhodes et al. 1987). Thus, the relationship observed in this study does not appear to be a general pattern.

In most cases, prevalences of each kind of hepatic lesion at each transect in Everett Harbor exceeded the corresponding value from Port Susan (Table 33). Concordance among the prevalences of the three kinds of lesion across all 11 transects was not significant (W=0.45, P>0.05).

Prevalence of neoplasms at the 10 Everett Harbor transects ranged from 0 to 8.8 percent, with the highest value observed at Transect NG-94. The prevalence of neoplasms at each transect in Everett Harbor did not differ significantly (P>0.001) from the prevalence of 0 percent observed at Port Susan.

Prevalence of foci of cellular alteration at Everett Harbor transects ranged from 0 to 21.1 percent, with the highest value observed at Transect NG-94. The prevalence of this lesion at each transect in Everett Harbor did not differ significantly (P>0.001) from the prevalence of 7.1 percent observed at Port Susan.

Prevalence of megalocytic hepatosis at Everett Harbor transects ranged from 0 to 14.3 percent, with the highest value observed at Transect EW-91. The prevalence of megalocytic hepatosis at each transect in Everett Harbor

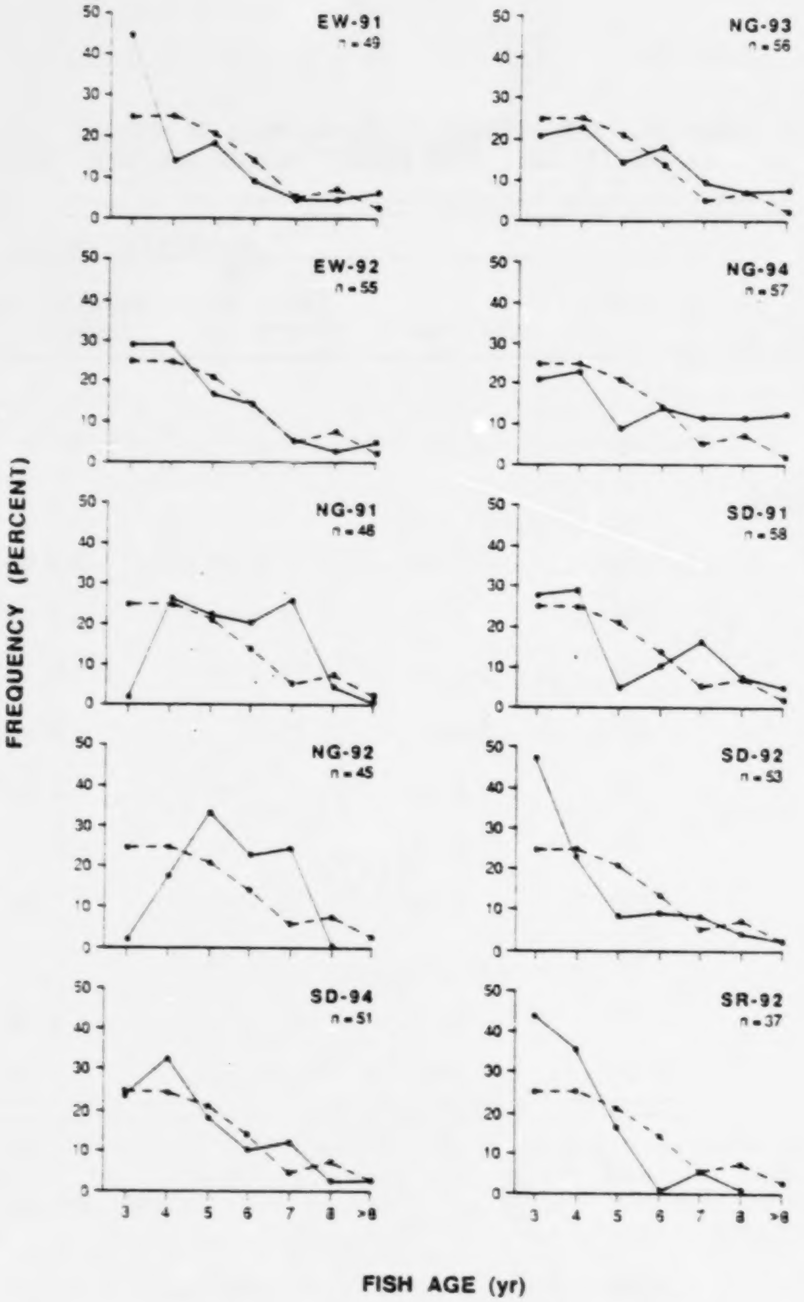


Figure 52. Comparisons of age distributions between Everett Harbor (solid lines) and Port Susan (dashed lines) transects.

TABLE 33. COMPARISONS OF PREVALENCES OF HEPATIC LESIONS IN ENGLISH SOLE FROM EVERETT HARBOR AND PORT SUSAN

Transect	Sample Size[a]	Prevalence (%)[b] Neoplasms	Foci of Cellular Alteration	Megalocytic Hepatosis	One or More Lesions
Port Susan					
PS-91	56	0	7.1	0	7.1
Everett Harbor					
NG-93	56	5.4 ns	17.9 ns	5.4 ns	21.4*
NG-92	45	0 ns	8.9 ns	0 ns	8.9 ns
NG-91	46	2.2 ns	10.9 ns	0 ns	13.0 ns
NG-94	57	8.8*	21.1*	0 ns	21.1*
EW-92	55	0 ns	0 ns	1.8 ns	1.8 ns
EW-91	49	2.0 ns	10.2 ns	14.3**	16.3 ns
SR-92	37	0 ns	8.1 ns	2.7 ns	8.1 ns
SD-91	58	1.7 ns	3.5 ns	0 ns	5.2 ns
SD-94	51	0 ns	13.7 ns	0 ns	13.7 ns
SD-92	53	1.9 ns	5.7 ns	1.9 ns	7.6 ns

[a] All fish were ≥ 3 years old, and the age distribution at each transect from Everett Harbor does not differ significantly ($P>0.05$) from the age distribution at Port Susan. Age distributions at Stations NG-91, NG-92, and SR-92 were adjusted before statistical comparisons (see text).

[b] Comparisons were made using the G-test of independence.
* = $P\leq 0.05$; ** = $P\leq 0.01$; ns = $P>0.05$.

did not differ significantly (P>0.001) from the prevalence of 0 percent observed at Port Susan.

Prevalence of one or more of the three kinds of hepatic lesions at Everett Harbor transects ranged from 1.8 to 21.4 percent, with the highest value observed at Transect NG-93. The prevalence of one or more of the three lesions at each transect in Everett Harbor did not differ significantly (P>0.001) from the prevalence of 7.1 percent observed at Port Susan.

The spatial distributions of the three kinds of hepatic lesions are presented in Figures 53-55. The highest prevalences of both neoplasms and foci of cellular alteration were found off Pigeon Creek and the Mukilteo Ferry Terminal. The highest prevalences of megalocytic hepatosis were found in the East Waterway and off the Mukilteo Ferry Terminal. The spatial distributions of the three kinds of hepatic lesion indicate that most abnormalities were found near the Mukilteo Ferry Terminal and along the shoreline in and near the East Waterway.

Comparison with Recent Historical Data

Results of the present study were compared with those from surveys conducted throughout Everett Harbor between 1979 and 1983 (Malins, D.C., 21 November 1984, personal communication; Malins et al. 1984, 1985, unpublished). Comparisons were limited to descriptive evaluations because different age distributions of English sole were examined in the two studies and because, in some cases, fish were collected at different locations and during different seasons. In making these comparisons, prevalences were averaged (if necessary) within five areas: the East Waterway (Transect EW-91), the Everett Waterfront (Transects EW-92 and NG-94), the Mukilteo area (Transect NG-93), the Snohomish River Delta (Transects SR-92 and SD-91), and Port Susan (Transect PS-91).

In general, the relative spatial patterns of lesion prevalences in the present study were similar to those found in earlier studies (Figure 56). In most cases, the prevalences of all three kinds of hepatic lesion were

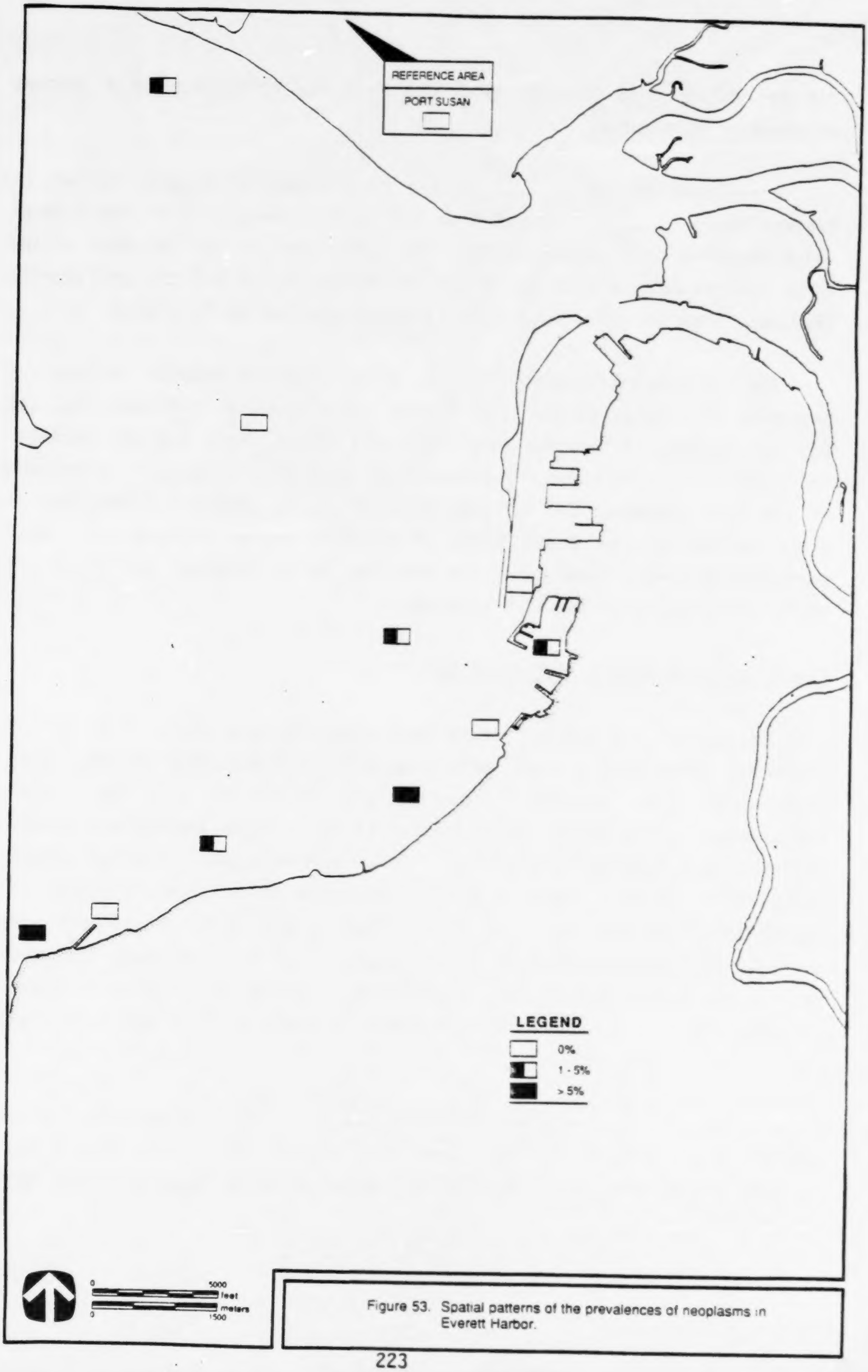

REFERENCE AREA
PORT SUSAN
LEGEND
0%
1 - 5%
> 5%
0
5000
feet
meters
0
1500

Figure 53. Spatial patterns of the prevalences of neoplasms in Everett Harbor.

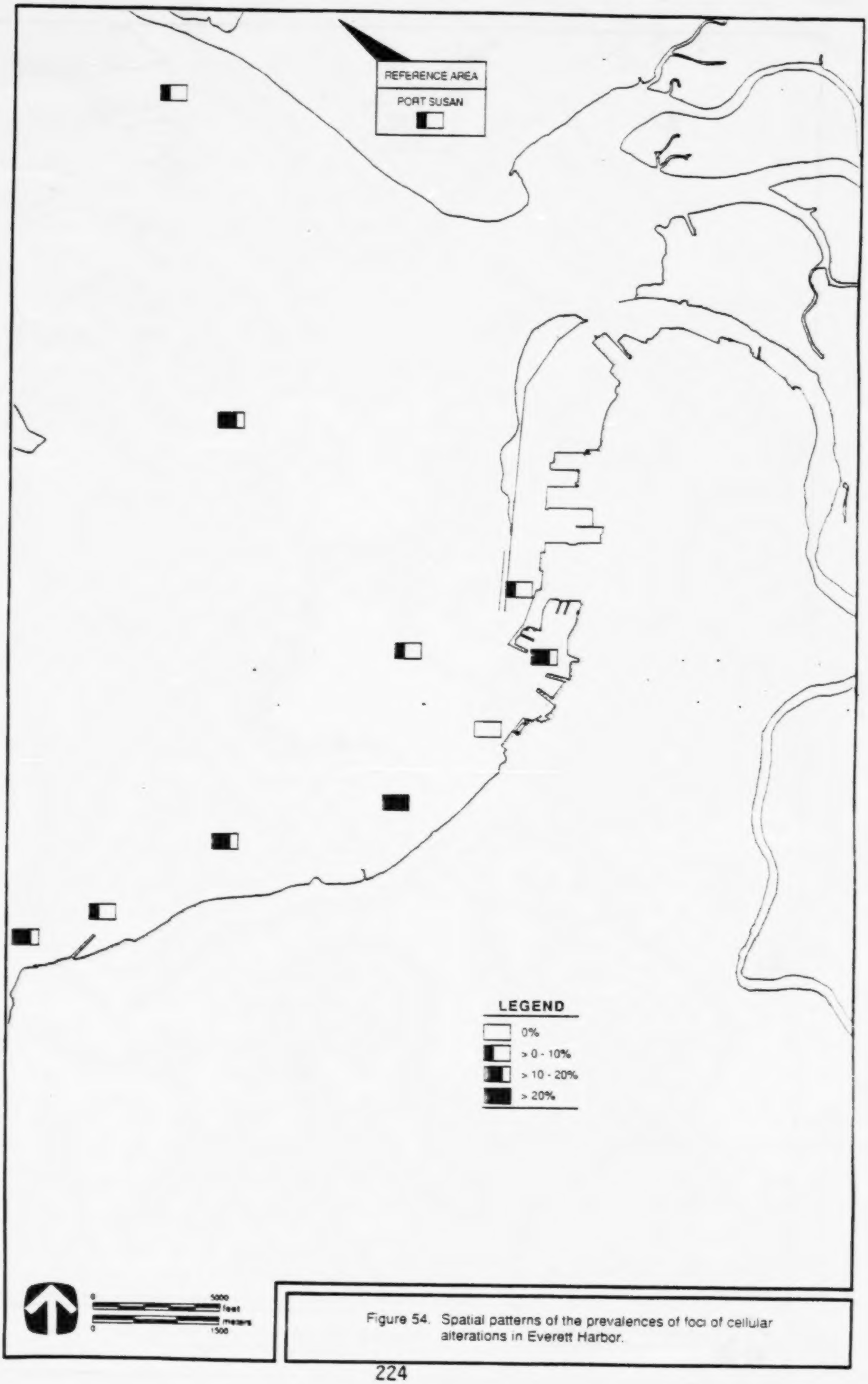

REFERENCE AREA
PORT SUSAN
LEGEND
0%
> 0 - 10%
> 10 - 20%
> 20%
0
5000
feet
meters
0
1500

Figure 54. Spatial patterns of the prevalences of foci of cellular alterations in Everett Harbor.

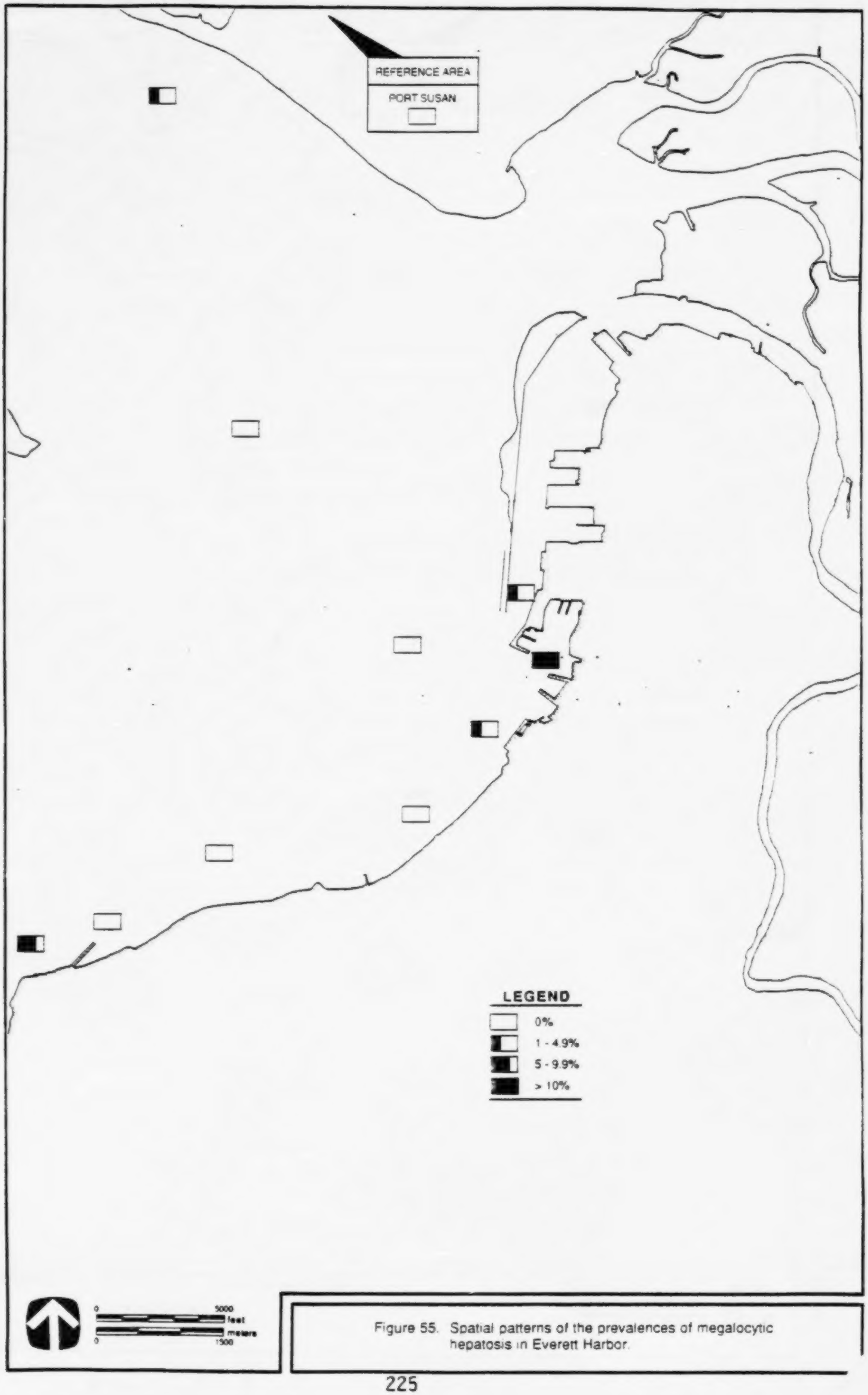

REFERENCE AREA
PORT SUSAN
LEGEND
0%
1 - 4.9%
5 - 9.9%
> 10%
0
5000
feet
meters
0
1500

Figure 55. Spatial patterns of the prevalences of megalocytic hepatosis in Everett Harbor.

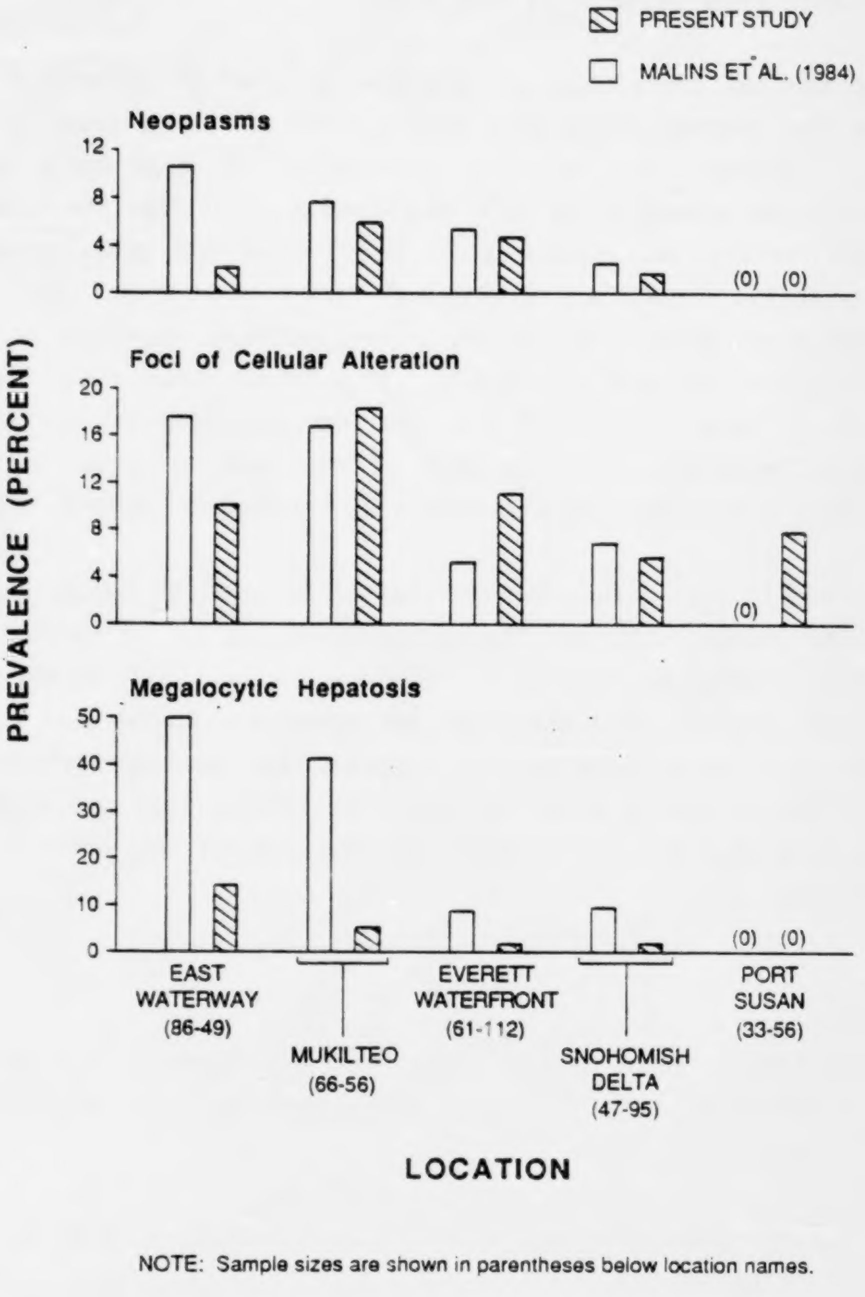


Figure 56. Comparison of prevalences of hepatic lesions in English sole sampled in the present study (stippled bars) and in Malins et al. (1984) (open bars).

higher along the shoreline between the East Waterway and Mukilteo than on the Snohomish River Delta or in Port Susan.

The absolute prevalences of neoplasms and foci of cellular alteration found in the present study were also similar to those found in earlier studies. However, the absolute prevalences of megalocytic hepatosis observed in the present study were considerably lower than the values found by the earlier studies. Rhodes et al. (1987) found that prevalences of this lesion exhibited significant interannual variation at eight sampling sites throughout Puget Sound. By contrast, prevalences of neoplasms and foci of cellular alteration did not exhibit significant interannual variation. Rhodes et al. (1987) suggested that the increased temporal variability of megalocytic hepatosis indicates that it may have different patterns of pathogenesis and progression than neoplasms and foci of cellular alteration.

The similarity in the relative spatial patterns of lesion prevalences between the present study and the studies conducted 3-7 yr earlier indicate that these patterns are real (i.e., they are not artifacts of the design of the various studies), and that they are relatively stable over time. The temporal stability of these patterns suggests that the causes of the lesions are localized primarily along the shoreline between the East Waterway and Mukilteo, and that the causes have not been reduced substantially between 1979 and 1986.

Summary

- Three kinds of hepatic lesion were considered in this study: neoplasms, foci of cellular alteration, and megalocytic hepatosis.

- Prevalences of neoplasms and foci of cellular alteration were correlated positively ($P \leq 0.05$) with fish age.

- Prevalence of megalocytic hepatosis was higher ($P \leq 0.05$) in males than in females.

- Prevalences of all three lesions at many of the 10 Everett Harbor transects were substantially elevated above reference values, but these differences were not statistically significant at P<0.001.

- The spatial distributions of the three kinds of hepatic lesions indicate that most abnormalities were confined to the shoreline between the East Waterway and Mukilteo.

- Results of the present study were compared with historical data collected 3-7 yr earlier. The relative magnitudes of lesion prevalences among areas were similar between studies. The absolute magnitudes of lesion prevalences were similar between studies for neoplasms and foci of cellular alteration. However, prevalences of megalocytic hepatosis were considerably lower in the present study than the values found in the earlier studies.

CONTAMINANT, TOXICITY, AND BIOLOGICAL EFFECTS RELATIONSHIPS

Quantitative relationships among the contaminant, toxicity, and biological effects variables used in the Everett Harbor investigation are examined in this section. The objectives of this section are to:

- Determine potential correlations between sediment contamination and benthic infauna depressions or toxicity to amphipods

- Compare amphipod bioassay mortality with effects on major taxa of benthic infauna.

The Everett Harbor database includes sediment chemistry and biological information at sites displaying a wide range of sediment contaminant levels. Therefore, the data were evaluated to detect correlations that may reflect potential cause-effect relationships. In this study, it was assumed that contaminants whose distributions were associated with biological effects had a higher potential for being causative agents than contaminants displaying no discernible relationships. However, demonstration of actual cause-effect relationships would require confirmation by laboratory toxicity experiments. Such studies were beyond the present scope, but may prove useful to support identification of toxic contamination problems in the future.

In a later section, the Puget Sound AET (Tetra Tech 1986c, 1987) are used to identify problem stations based on sediment chemistry data from previous studies where appropriate biological effects data were unavailable (see **Prioritization of Problem Areas and Contaminants**). As part of an ongoing EPA project, the contaminant-effects data from the Everett Harbor investigation will be incorporated into the SEDQUAL database to derive updated AET.

RELATIONSHIPS AMONG CONTAMINANTS, TOXICITY, AND BENTHIC EFFECTS

This section examines the correspondence between the physical-chemical characteristics of sediments and their toxicity to amphipods or observed impacts on indigenous benthic infaunal taxa.

General Correlation of Indicators

Significant amphipod mortality relative to reference was found at four of the 29 test sites in the Everett Harbor system ($P<0.001$; see Figure 40). Significant benthic effects were observed at 11 of the 16 stations sampled for benthic infauna (see Figure 50). In these analyses, benthic effects were defined as a statistically significant ($P<0.001$) depression in at least one of four major taxa (Polychaeta, Pelecypoda, Gastropoda, Crustacea) relative to conditions at the Port Susan reference area.

Significant bioeffects were measured in at least one of the site-specific biological tests at all four stations where EAR exceeded 1,000 for at least one problem chemical in sediments (Stations EW-04, EW-07, EW-10, and EW-14 in Table 20). In other sediments where there were no significant toxic responses and benthic effects (i.e., Stations NG-06, NG-10, and SD-02), concentrations of organic compounds classified as problem chemicals were generally low (EAR<30), but sometimes exceeded AET. For example, the concentration of 4-methylphenol was 1,800 ug/kg DW (EAR=140), or 1.5 times the HAET, at Station NG-10. EAR for problem metals at stations without significant biological effects ranged up to only about three times reference conditions (zinc at Station SD-02) and were always less than AET.

Examples of relationships between biological variables and physical/chemical variables are shown in Figures 57-62. These figures were selected from a complete set of scatterplots developed for the following variables:

- **Chemicals:** LPAH, HPAH, naphthalene, phenol, 4-methylphenol, pentachlorophenol, 2,4,6-trichlorophenol, 3,4,5-trichloroguaiacol, abietic acid, dehydroabietic acid, 12-chlorodehydro-

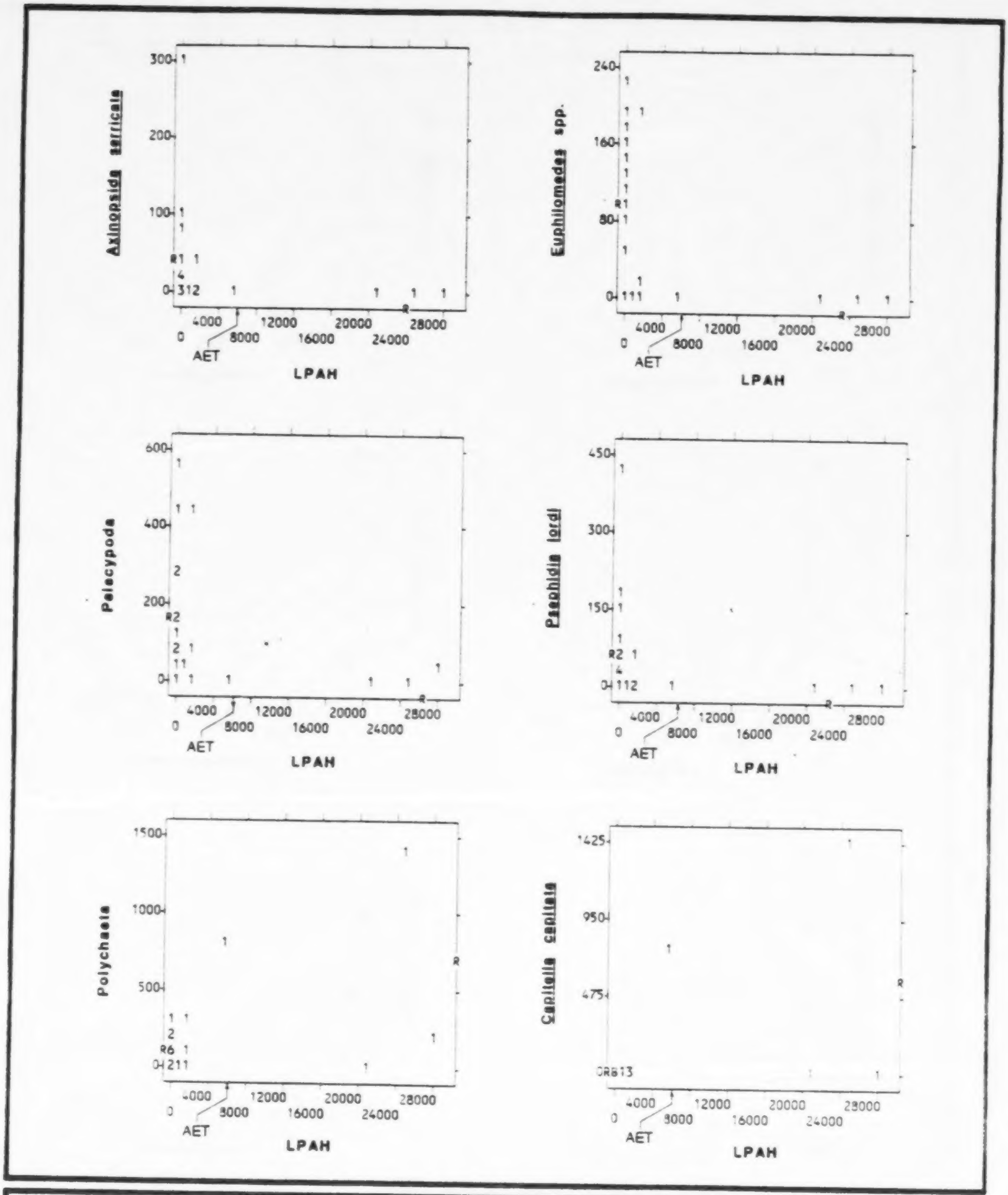


Figure 57. Relationships between abundances (no./0.1 m^2) of selected benthic taxa and LPAH concentration (µg/kg dry weight) in sediments.

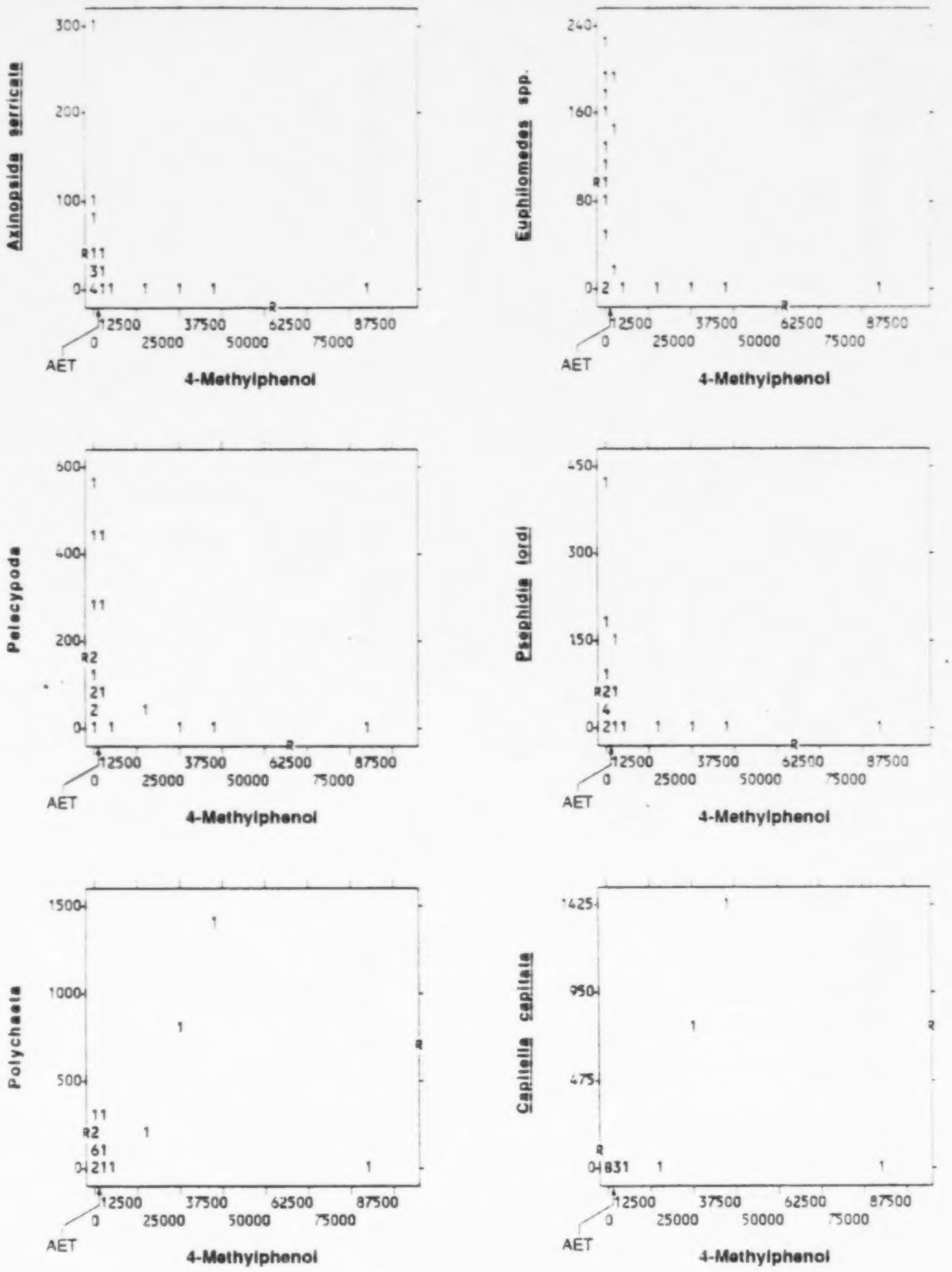


Figure 58. Relationships between abundances (no./0.1 m^2) of selected benthic taxa and 4-methylphenol concentration (µg/kg dry weight) in sediments.

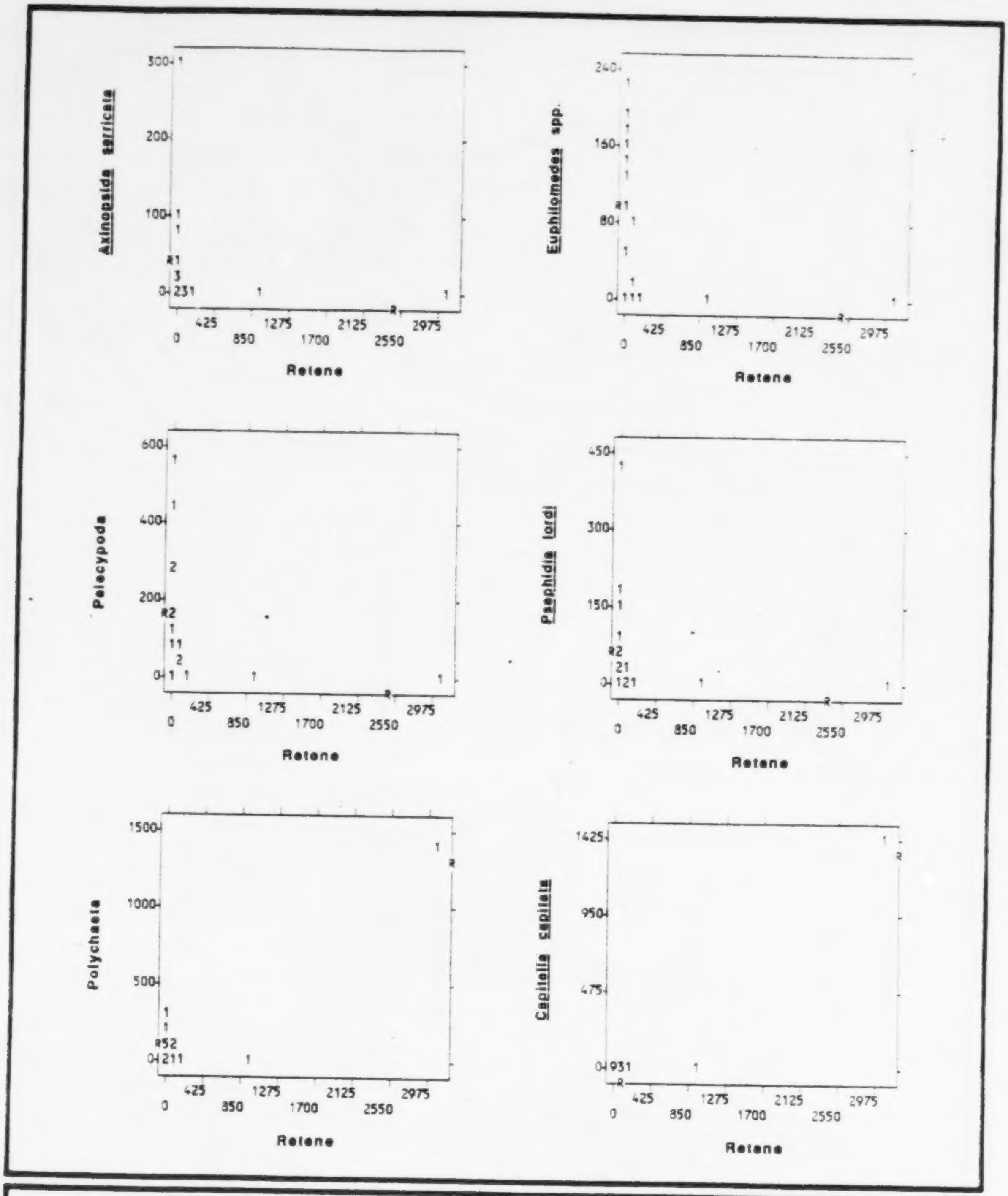


Figure 59. Relationships between abundances (no./0.1 m^2) of selected benthic taxa and retene concentration (µg/kg dry weight) in sediments.

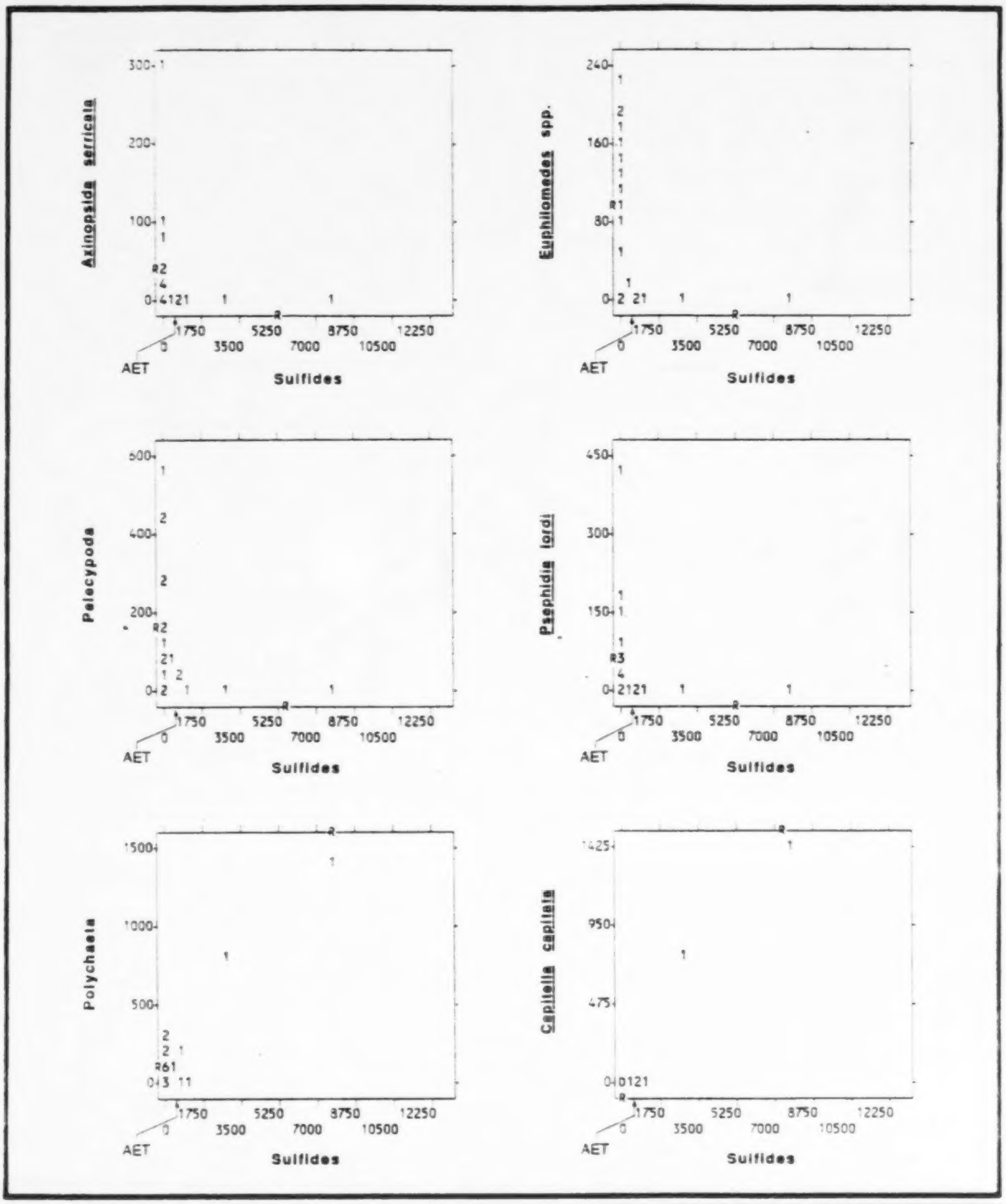


Figure 60. Relationships between abundances (no./0.1 m^2) of selected benthic taxa and sulfides concentration (mg/kg dry weight) in sediments.

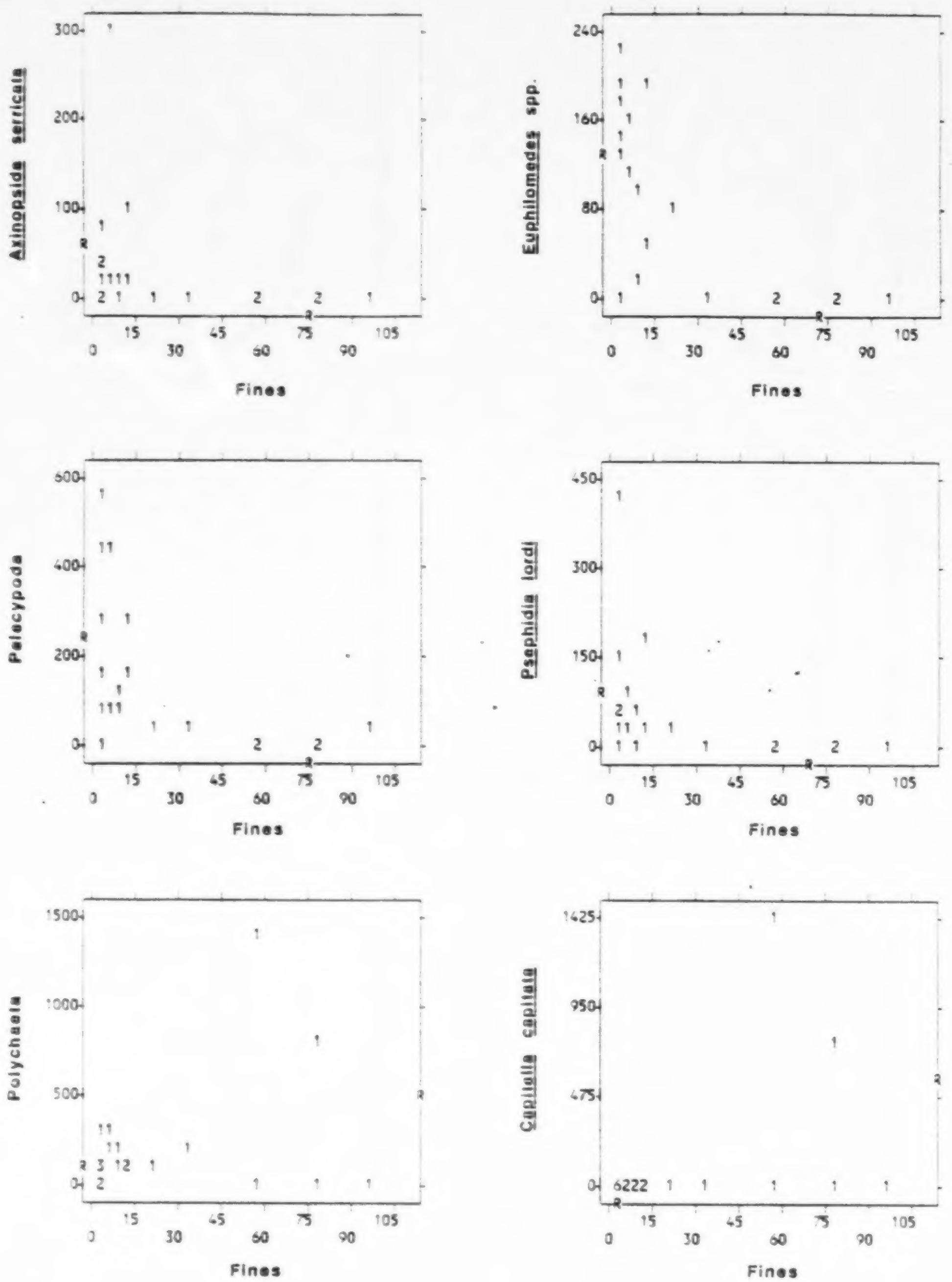


Figure 61. Relationships between abundances (no./0.1 m^2) of selected benthic taxa and sediment grain size (percent fine-grained material).

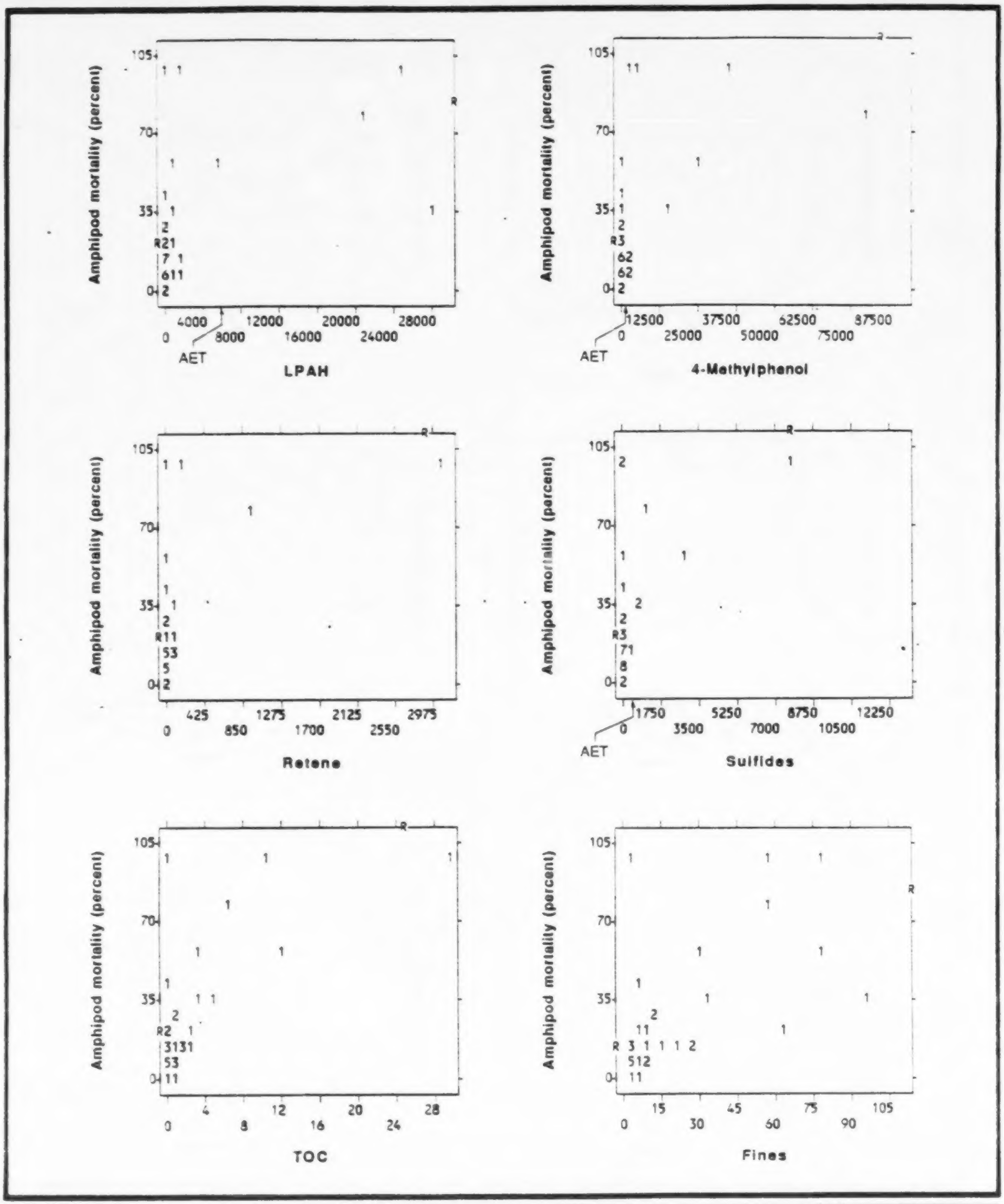


Figure 62. Relationships between amphipod bioassay response (percent mortality) and LPAH (µg/kg dry weight), 4-methyl phenol (µg/kg dry weight), retene (µg/kg dry weight), sulfides (mg/kg dry weight), and TOC (percent dry weight) in sediments.

abietic acid, benzoic acid, retene, a cymene isomer, and sulfides

- **Benthic taxa:** *Capitella capitata* (Polychaeta), *Euphilomedes* spp. (Crustacea), *Psephidia lordi* (Pelecypoda), *Axinopsida serricata* (Pelecypoda), Crustacea, Gastropoda, Pelecypoda, and Polychaeta
- **Amphipod bioassay mortality.**

The chemicals listed above were selected for this analysis mainly because of their high detection frequency, high concentration, potential toxicity, potential value as tracers of pollutant sources, or some combination of these attributes. Concentrations of most of the selected chemicals were greatly elevated above corresponding reference values. Conventional sediment variables [sulfides, TOC, and grain size (percent fine-grained material)] were also entered in the analysis. Relationships of biological variables to metals in sediments were not examined because metals concentrations were not substantially elevated in the study area. The benthic species listed above were selected because they were widely distributed in the project area and they represented the dominant species within their respective major taxa at selected stations. *C. capitata* was also selected because it is well known as a pollution-tolerant species. The examples shown in Figures 57-62 were chosen because they illustrate some of the clearest relationships between physical/chemical and biological variables. The results for Polychaeta and Pelecypoda were selected because among major taxa they exhibited the most depressions in abundance relative to Port Susan (see **Benthic Macroinvertebrates** in **Results** section). Relationships of biological variables to conventional variables (e.g., sulfides, percent fine-grained material) are shown to provide perspective in interpreting relationships between biological variables and toxic chemicals.

A common feature of the relationship between sediment chemistry and biological variables is the wide scatter in the sediment toxicity and taxa abundances at lower chemical concentrations (Figures 57-60 and 62). This scatter is expected when relating a single chemical (or related group of chemicals) to a biological variable because at lower concentrations of the chemical the biological variable could be more strongly influenced by an unrelated chemical or other factors. For the selected chemical variables (LPAH, 4-methylphenol, retene, and sulfides in Figures 57-60 and 62), the primary trend observed was the consistent occurrence of high values of sediment toxicity and low values of benthic taxa abundances at higher concentrations of the chemicals evaluated. Aside from C. capitata and its respective higher taxon (Polychaeta), all of the taxa analyzed were consistently low in abundance at stations with higher concentrations of chemicals, including some of the other chemicals analyzed but not shown here (e.g., HPAH, phenol). C. capitata was extremely abundant at Station EW-04 despite high concentrations of many chemicals at that station. TOC content in sediments at Station EW-04 was 29 percent, the highest value observed in the study and among the highest values found in polluted areas of Puget Sound. High abundance of C. capitata is typically an indicator of disturbed conditions, especially organically-enriched habitats.

Most taxa exhibited consistently low abundances at higher concentrations of sulfides, except C. capitata and Polychaeta, which displayed an apparent linear increase with sulfide concentration (Figure 60; $r=0.98$, $n=19$, $P<0.001$ and $r=0.94$, $n=19$, $P<0.001$, respectively). These apparently linear relationships were each driven by two points (see Figure 60) and therefore should be considered tentative. Nevertheless, a clear positive relationship between the abundance of C. capitella and sulfide concentration in sediments was found in a recent study of Elliott Bay ($r=0.70$, $n=18$, $P<0.05$) (PTI and Tetra Tech 1988).

Sediment toxicity as measured by mortality in the amphipod bioassay was generally high at higher concentrations of 4-methylphenol, retene, sulfides, and TOC (see Figure 62). No clear relationship was found between amphipod mortality and LPAH or HPAH. The amphipod bioassay has previously been shown to be insensitive to a wide range of PAH concentrations in the environment (e.g., Tetra Tech 1986d). The data for the other chemical variables used in this analysis were too limited to evaluate their relationships to amphipod mortality.

Because fine-grained sediments were found mainly in the East Waterway where chemical concentrations were also highly elevated (see **Sediment Chemistry** in **Results** section), the covariance of chemical variables (including sulfides) with sediment grain size probably explains the observed relationships between several benthic taxa and percent fine-gained material (see Figure 61). To minimize the importance of chemical factors relative to physical structure of the sediments, the relationship of benthic infauna abundance to grain size was examined using only reference area data. Based on data from seven stations in Port Susan (1985 and 1986 data combined), there was no apparent relationship between the abundances of Pelecypoda, Axinopsida serricata, and Psephidia lordi and percent fine-grained material. Although pelecypods were relatively less abundant at the station with the largest fraction of fine-grained material (Station PS-01, 1985, 88 percent fine-grained material), their relationship to sediment grain size was clearly nonlinear, with maximum abundances achieved at stations with about 24 percent fine-grained material. At the Port Susan stations, Gastropoda showed no clear relationship to grain size. The greatest abundance of gastropods was found at Station PS-01 in 1985, with 88 percent fine-grained material.. Euphilomedes spp. showed a trend toward increased abundances in coarse-grained sediments based on the Port Susan stations, but the variation with grain size (on the order of 2-4 times) cannot account for the large differences in abundance between some stations in Figure 61.

A positive linear correlation was found between amphipod mortality and percent fine-grained material in sediments, although the relationship does not explain much of the variance in amphipod response ($r=0.57$, $n=32$, $P<0.001$). Only 33 percent of the variance is explained by a regression of percent mortality against percent fine-grained material [$Y=0.641X+13.4$ (standard error of slope=$\pm$0.168; standard error of intercept = 5.68)]. The relationship between amphipod mortality and fine-grained material in Figure 62 is confounded by high chemical contamination at some stations with very fine-grained sediments. Using only the data for seven sediment samples from Port Susan (1985 and 1986 reference area data combined), no relationship between the amphipod response and sediment grain size was found.

DeWitt et al. (1988) developed a relationship between Rhepoxynius abronius mortality and percent fine-grained material in sediments from eight reference areas of Puget Sound. Using the method of DeWitt et al. (1988) to correct for the effects of sediment grain size, all samples with mean mortality values identified as significantly different ($P<0.05$ or $P<0.001$) from reference in the present study would still be classified as toxic (see **Sediment Bioassays** in **Results** section). The regression equation derived by DeWitt et al. (1988) explained approximately 29 percent of the variance in the relationship between amphipod mortality and percent fine-grained material. Although DeWitt et al. (1988) were able to demonstrate experimentally that very fine sediments in the silt-clay size range decreased amphipod survival relative to survival in coarser sediments, they concluded that particle size could not account for all of the background mortality in reference area sediments. Moreover, they concluded that particle size is probably just a variable that is strongly correlated with the actual cause of mortality. In any case, the high amphipod mortalities found for several stations in the present study cannot be explained by the effects of sediment grain size alone.

Relationships Between Chemical and Biological Variables in the East Waterway

Because the most severe chemical contamination and associated biological effects were found in the East Waterway, relationships between chemical and biological variables were examined further for this area (Figure 63). Six stations along a nearshore transect formed the main basis for this analysis: Stations EW-01, EW-04, EW-07, EW-10, EW-12, and EW-14 in order from north to south. Two additional stations (Stations NG-01 and NG-02) from the adjacent area immediately south of the East Waterway were also included to provide perspective based on relatively uncontaminated conditions. Chemicals selected for this analysis included LPAH, 4-methylphenol, 2,4,6-trichlorophenol, dehydroabietic acid, and sulfides. All of these chemicals exhibited elevated concentrations in the East Waterway and are representative of important compound classes in that area. LPAH represents a group of six PAH compounds, with naphthalene as a predominant component in East Waterway sediments. Relationships between biological variables and HPAH were similar to those shown for LPAH. 4-Methylphenol, an alkyl-substituted phenol, was a

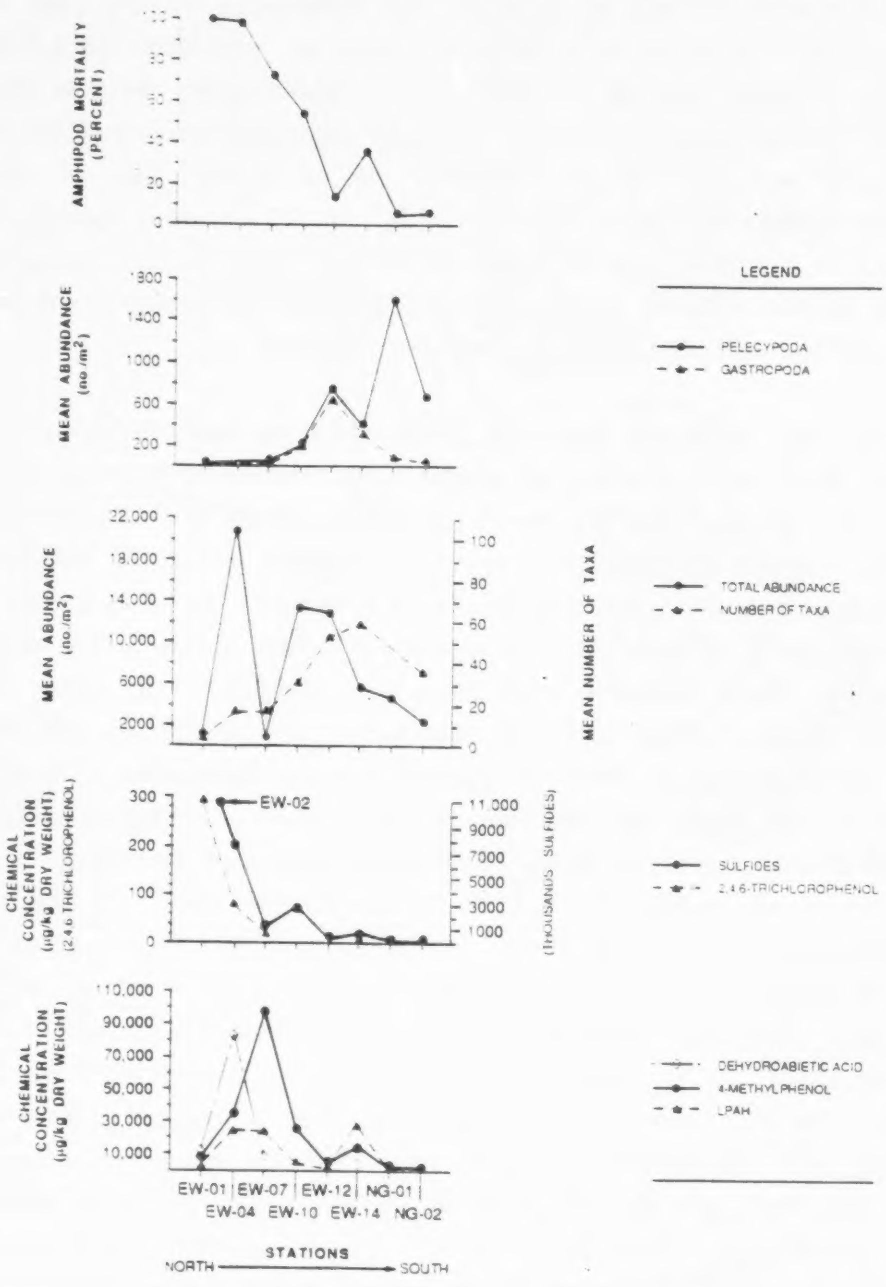


Figure 63. Relationships between selected biological and chemical variables in the East Waterway and adjacent areas.

problem chemical that occurred at substantially elevated concentrations throughout much of the study area, but especially in the East Waterway. Dehydroabietic acid, a resin acid, occurred at very high concentrations in the East Waterway and had the highest EAR values among resin acids. 2,4,6-Trichlorophenol occurred at less elevated concentrations than the compounds above, but was selected to represent the covarying class of chlorinated phenolic compounds (chlorinated phenols and chlorinated guaiacols) often reported in bleached pulp effluents. Sulfides were included in the analysis because of their known association with pulp mill discharges and because of their extreme concentrations in the East Waterway.

The data shown in Figure 63 indicate a maximum biological impact at Station EW-01 and a gradient of generally decreasing effects toward Stations NG-01 and NG-02. Station EW-14 exhibited slightly increased biological effects relative to adjacent stations. Amphipod mortality was 100 percent at Station EW-01 and generally decreased from north to south toward Stations NG-01 and NG-02 (Figure 63). A moderate increase in mortality was observed at Station EW-14 compared with adjacent stations. The total number of benthic infaunal taxa and the abundances of Gastropoda and Pelecypoda increased from Station EW-01 to Station EW-12. The number of taxa remained generally high along the remainder of the transect, decreasing slightly from Station EW-14 to Station NG-02. Gastropoda abundance decreased consistently and Pelecypoda abundance fluctuated from Station EW-12 to Station NG-02. The abundance of total Mollusca generally increased from Station EW-01 to Station NG-01, with a decrease at Station EW-14 relative to adjacent stations. The total abundance of benthic infauna fluctuated greatly from Station EW-01 to Station EW-10 and decreased thereafter toward Station NG-02. The high abundances of the polychaete *C. capitata*, the crustacean *Nebalia* spp., and nematode worms at Stations EW-04 and EW-10 account for the peaks in total infauna abundance at these sites. The high abundances of these opportunistic taxa and the relatively low number of total taxa indicate severely disturbed conditions in the benthic assemblages at these sites. The crustacean *Leptochelia* spp. accounted for the high abundance of total infauna at Station EW-12. The presence of this taxon and the relative increase in total number of taxa indicate less disturbed conditions compared with other sites in the East Waterway.

The general pattern of chemical contamination among these stations corresponded to the biological effects pattern (see Figure 63). However, the distribution of chemical concentrations among stations differed among specific chemicals. The clearest gradient relationships between single chemicals and biological variables were found for sulfides and 2,4,6-trichlorophenol. Concentrations of sulfides and 2,4,6-trichlorophenol generally decreased from the head of the East Waterway to Stations NG-01 and NG-02. Other chemicals that displayed maximum concentrations at Station EW-01 included sandaracopimaric acid, 2,4-dichlorophenol, 2,3,4,6-tetrachlorophenol, 3,4,5-trichloroguaiacol, 4,5,6-trichloroguaiacol, and tetrachloroguaiacol. In contrast to the distribution pattern shown by sulfides and 2,4,6-trichlorophenol, the concentrations of LPAH, 4-methylphenol, and dehydroabietic acid at Station EW-01 appeared relatively low compared to Stations EW-04 and EW-07. Dehydroabietic acid concentrations maximized at Station EW-04 and 4-methylphenol concentrations maximized at Station EW-07. Finally, concentrations of LPAH, 4-methylphenol, and sulfides were higher at Station EW-14 relative to those at Stations EW-12 and NG-01, corresponding to the increased biological effects at that site. It should be emphasized that the general pattern of decreasing chemical contamination and decreasing biological effects from north to south in the East Waterway (see Figure 63) may not represent the actual fine-scale pattern of chemical and biological conditions. Chemical concentrations at additional stations in the waterway where biological variables were not measured suggest a complex pattern of contamination at nearshore stations (see **Sediment Chemistry** in **Results** section). Most notably, Station EW-13, which was not tested for site-specific biological effects, had very elevated concentrations of certain chemicals related to the pulp industry (e.g., the highest concentrations of abietic acid, neoabietic acid, and isopimaric acid in the study).

Two potential patterns of chemical distribution and effects may be invoked to explain the apparent decrease in biological effects from the head of the East Waterway to stations along the southern shore of Port Gardner (see Figure 63). First, a gradient in concentrations of a chemical or of a group of chemicals may correspond to the observed trend in biological impacts (e.g., sulfides, chlorinated phenols). Second, a pattern of transition from one dominant chemical to another in a complex mixture may account for the gradient in observed biological effects (e.g., transition from maximum sulfides at the head of the East Waterway to maximum dehydroabietic acid at Station EW-04 to maximum 4-methylphenol at Station EW-07). Although the specific chemical or suite of chemicals responsible for biological effects probably varies among stations, the major biological impacts observed at Stations EW-01, EW-04, and EW-07 are likely related to pulp mill discharges. The contributions of variations in percent fine-grained material and TOC to the observed pattern of biological effects is probably minor, as discussed previously. The extreme depressions of benthic infauna and the high bioassay mortalities observed at selected stations in the East Waterway cannot be accounted for by variations in physical structure and organic carbon content of the sediments.

Comparison of Contamination and Significant Biological Effects

Both sediment toxicity and the number of significant benthic effects were generally high at the most contaminated stations. Among the 23 priority (Tier II) problem stations identified in the next chapter (see **Prioritization of Problem Areas and Contaminants**), HAET were exceeded for at least one chemical at 21 stations. Of these 21 stations, sediment toxicity to amphipods, benthic infauna abundances, or both were evaluated at 12 stations. Eight of these 12 stations (=67 percent) displayed significant toxicity to amphipods, depressions in the abundances of major taxa of benthic infauna, or both ($P<0.001$). At the four problem stations without significant biological effects (Stations ES-03, EW-12, NG-10, and NG-14), concentrations of problem chemicals were not substantially higher than HAET (1-3 times HAET, with a mean of 1.9 times HAET). Seven of the eight stations with significant effects exhibited severe biological effects that were sufficient for problem area definition (i.e., >40 percent amphipod mortality or ≥80 percent depression of at least one major taxa of infauna). Three stations that exhibited severe effects for both the amphipod bioassay and indigenous benthic assemblages were among the highly contaminated sites in the Everett Harbor system. These three stations are listed below:

- **Station EW-01**, located in the East Waterway, exhibited exceedances of HAET for phenol and 4-methylphenol in sediments. Maximum concentrations in the study area were also observed for sandaracopimaric acid, 2,4-dichlorophenol, 2,4,6-trichlorophenol, 2,3,4,6-tetrachlorophenol, 3,4,5-trichloroguaiacol, 4,5,6-trichloroguaiacol, and tetrachloroguaiacol (AET are not available for these compounds).

- **Station EW-04**, located in the East Waterway, displayed HAET exceedances for LPAH, 4-methylphenol, phenol, 2-methylphenol, 2,4-dimethylphenol, benzyl alcohol, PCBs, 1,2-dichlorobenzene, and TOC. The dehydroabietic acid concentration at this station exceeded an EAR of 1,000 (no AET is available for DHA). Many other compounds (e.g., all chlorinated resin acids, PCP, 2-chlorophenol, and most TIO compounds) had maximum concentrations at this station.

- **Station EW-07**, located in the East Waterway, exhibited HAET exceedances for LPAH, 4-methylphenol, 2-methylphenol, and 2,4-dimethylphenol.

Concordance between the biological and chemical results at these stations and others that exhibited significant biological effects was generally reflected in similar priority rankings based on chemical vs. biological variables (see **Prioritization of Problem Areas and Contaminants**).

Although either severe sediment toxicity or effects on benthic infauna were usually observed at highly contaminated sites, one exception to this trend is notable. Significant, but not severe, biological effects were found at Station EW-14 which had highly contaminated sediments exceeding HAET for the following chemicals: LPAH, phenol, 4-methylphenol, dibenzofuran, benzoic acid, copper, and zinc. Among stations in the Tier II problem areas with a full complement of biological indicators, Station EW-14 was the only station that exhibited a difference of at least 30 percent between the separate priority scores based on chemistry and biology (see below, **Prioritization of Problem Areas and Contaminants**). Nevertheless, increased biological effects were apparent at Station EW-14 relative to adjacent sites (see Figure 63). Also, the abundance of pelecypods was significantly reduced at Station EW-14 compared to Port Susan reference conditions ($P<0.001$).

Severe biological effects observed in this study were rarely associated with low chemical contamination (i.e., concentrations below AET). Severe biological effects were sufficient for definition of a problem area at only one station (Station SD-01) where chemical contamination was relatively low (i.e., where LAET were not exceeded for any chemical). Several benthic taxa displayed >80 percent depression at Station SD-01. However, swift currents within the delta channel where this station was located (as indicated by bathymetry and coarseness of the sediments) may be responsible for disturbance of the benthic community. The concentration of sulfides at Station SR-07 was 600 mg/kg DW, which is in the range of amphipod and benthic AET (540-630 ug/kg DW) currently being developed under a separate EPA project. Severe depressions in abundances of gastropods, pelecypods, and polychaetes were observed at Station SR-07. The low abundances of benthic infauna at this site may be caused partly by the extreme sediment texture (95.5 percent fine-grained material) or periodic hypoxia due to poor flushing within the marina. Also, TBT was detected in a sediment sample from Station SR-07.

In conclusion, significant ($P\leq0.001$) biological effects as measured by the amphipod toxicity bioassay and reductions in abundances of benthic infauna taxa were generally associated with high concentrations of contaminants in sediments. At the four problem stations without significant biological effects (Stations ES-03, EW-12, NG-10, and NG-14), concentrations of problem chemicals were not substantially higher than HAET.

COMPARISON OF BIOASSAY RESPONSES WITH BENTHIC INVERTEBRATE ASSEMBLAGES

This section examines the degree of consistency between bioassays and benthic infauna as indicators of environmental contamination. The amphipod bioassay represented the acute (10-day) response of an individual species (Rhepoxynius abronius) to sediment removed from its natural setting, whereas benthic infauna represented the in situ, acute and chronic (weeks to months) responses of groups of organisms (i.e., major taxa). The objectives of the following sections are to determine whether the two indicators were correlated or displayed similar patterns of statistically significant differences from reference conditions. Because the two indicators measure somewhat independent biological responses, complete concordance between bioassay and benthic infauna results is not expected. Comparisons of bioassay responses with abundances of benthic infauna taxa were based on the 16 stations in the Everett Harbor system and the three stations in Port Susan at which both indicators were evaluated.

Correlation of Indicators

The abundances of Amphipoda and Gastropoda were each consistently low at stations that exhibited a mean mortality greater than about 50 percent in the amphipod bioassay (Figure 64). Thus, the relationship between percent mortality in the bioassay and the abundance of amphipods was characterized by a response region (i.e., area of consistently low mortality) rather than a simple linear function (Figure 64). The abundances of Polychaeta and Pelecypoda were not clearly related to amphipod mortality.

PTI and Tetra Tech (1988) found distinct response regions in the relationships between amphipod mortality and abundances of several infaunal taxa. For example, the abundances of *Euphilomedes*, *P. lordi*, and total crustaceans were consistently low at mean amphipod mortalities above 50 percent. The amphipod mortality bioassay was a good predictor of the response of these taxa at ≥50 percent amphipod mortality. Below 50 percent mortality in the bioassay, the response of all benthic taxa evaluated was variable.

Tetra Tech (1985a) reported a lack of linear relationships between the amphipod bioassay response and the abundances of the following major taxa in the Commencement Bay system: Polychaeta, Mollusca, Crustacea, Echinodermata, and total taxa. Similarly, PTI and Tetra Tech (1988) did not find simple linear relationships between amphipod mortality and the abundances of *Euphilomedes* spp., *Psephidia lordi*, *Odostomia* spp., Pelecypoda, and Crustacea. As noted in the latter report, the wide range of abundances of

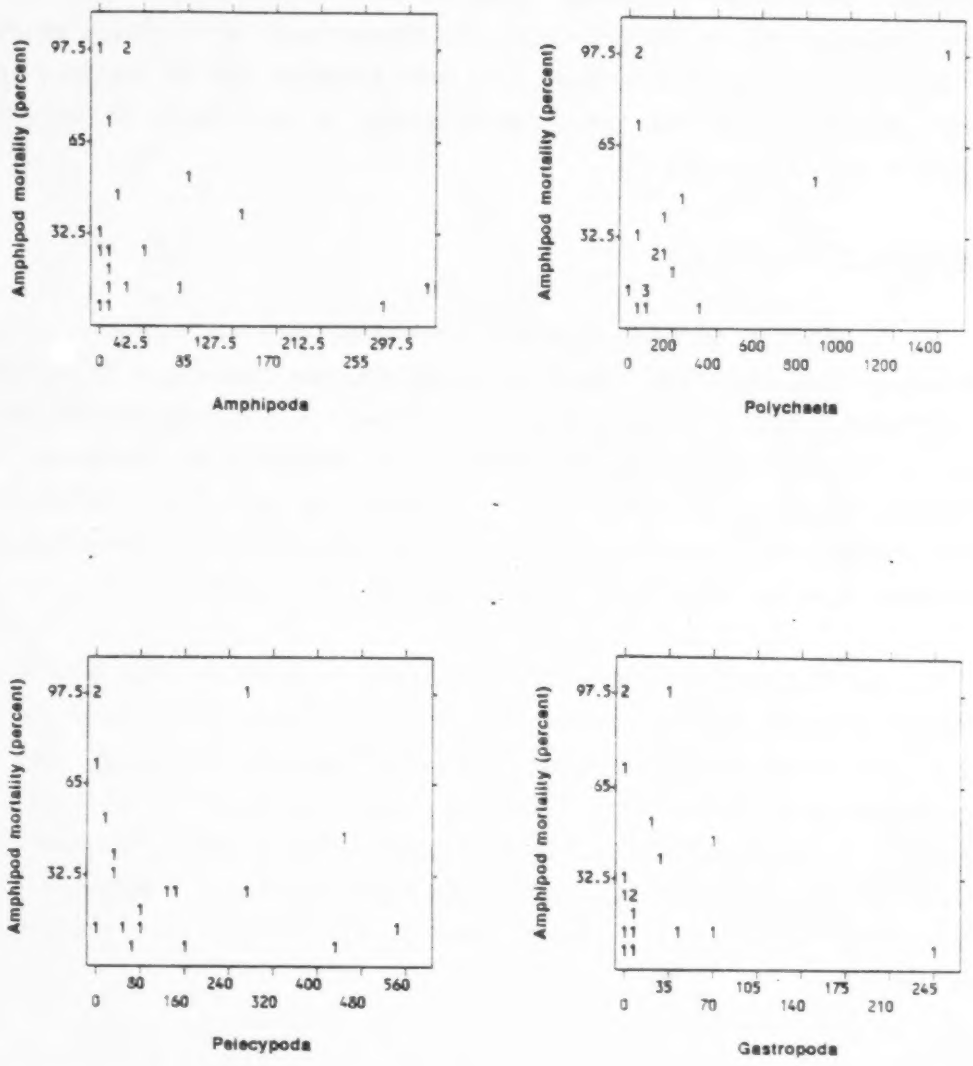


Figure 64. Relationships between abundances of selected benthic taxa (no./0.1 m^2) and amphipod bioassay response (percent mortality).

infaunal taxa at lower mortality levels in the amphipod bioassay (Figure 64) may be explained by the potentially higher sensitivity of indigenous benthic assemblages to toxic chemicals. This higher relative sensitivity of the infaunal assemblages could result from chronic exposure (compared to short-term exposure in the bioassay) or exposure of sensitive juvenile stages (compared with exposure of adult organisms in the bioassay).

Comparison of Bioassay Responses with Benthic Groupings

Values of amphipod mortality were compared with the groupings of stations determined by classification analysis of benthic invertebrate assemblages (see above, **Benthic Macroinvertebrates** in **Results** section). The results of this comparison show that the mean level of amphipod mortality differed among groups of stations that differed in benthic infaunal characteristics (Figure 65). The mean bioassay mortality among benthic infaunal Group I stations displayed a large range (5-100 percent mortality) relative to other benthic infaunal groups. Most stations in Group I displayed mean amphipod mortalities of less than 35 percent. Amphipod mortalities at stations in benthic infaunal Group II ranged from 5 to 37 percent, with a mean of 18 percent. The stations in Groups I and II each exhibited one or no significant depressions ($P<0.001$) of the four major taxa used to define problem areas (i.e., Polychaeta, Pelecypoda, Gastropoda, and Crustacea). At Group I Station NG-04, only the abundance of polychaetes was significantly lower than reference conditions ($P\leq0.001$) despite an observation of 100 percent mortality in the amphipod bioassay. Group III stations displayed high amphipod mortalities, ranging from 55 to 100 percent with a mean of 82 among stations. The abundance of at least one major taxon of benthic infauna was significantly depressed at all four stations in Group III. Pelecypod abundances were significantly depressed at all four stations in Group III ($P\leq0.001$). At Stations EW-01 and EW-07, the abundances of polychaetes and gastropods were also significantly reduced relative to reference conditions ($P\leq0.001$). Group III stations exhibited several characteristics indicative of extremely stressed conditions, including depressions in the abundances of major taxa and dominance by pollution-tolerant species (see Figure 63 and **Benthic Macroinvertebrates** in **Results** section).

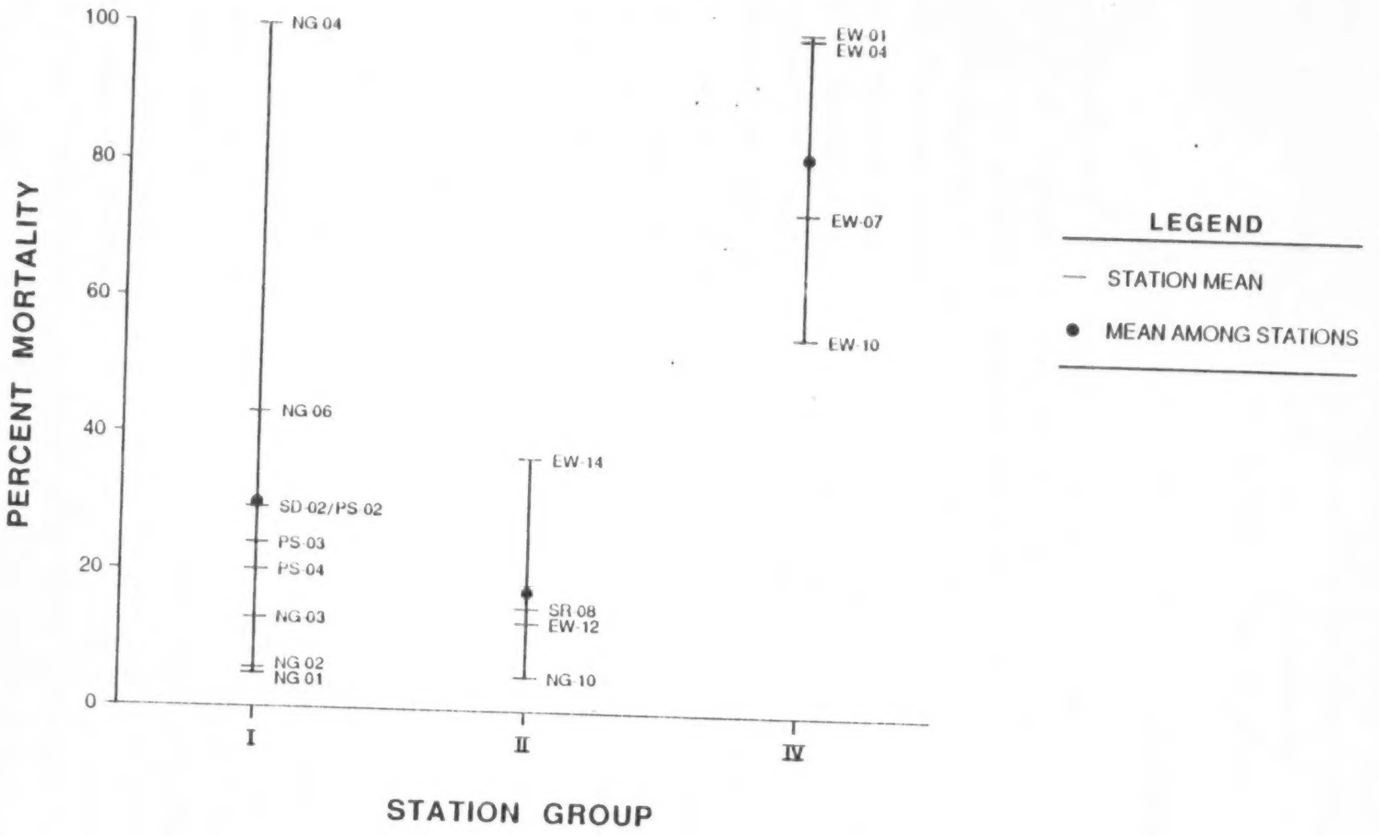


Figure 65. Amphipod bioassay responses in relation to station groupings based on classification analysis of benthic assemblages.

In conclusion, stations that exhibited the most severe benthic effects also displayed the highest toxicity levels found in the study. These stations were all located in the East Waterway. Mean amphipod mortality was generally less than 50 percent at stations with little or no effects on benthic infauna. A similar finding was reported by Tetra Tech (1985a) and PTI and Tetra Tech (1988).

Comparison of Significant Responses

The relationship of significant mortality in the amphipod bioassay to the occurrence of at least one significant depression of a major taxa of benthic infauna is presented in Table 34. Overall, the concordance in the responses of the bioassay and infauna was 56 percent (i.e., the percentage of stations showing consistent responses was about 56 percent). Because of the small sample size (n=16 stations), concordance for the study area as a whole was not substantially better than that expected by chance alone (i.e., 50 percent). Concordance between the bioassay and benthos was found at highly contaminated sites, especially in the East Waterway (see above, **General Correlation of Indicators** in **Relationships among Contaminants, Toxicity, and Benthic Effects** section). The lack of study-wide concordance between significant responses in the amphipod bioassay and in benthic infauna despite strong concordance within geographically distinct problem areas was also reported by Tetra Tech (1985a) and PTI and Tetra Tech (1988) for Commencement Bay and Elliott Bay, respectively.

SUMMARY

- Biological effects as measured by the amphipod toxicity bioassay and significant reductions in abundances of benthic infauna taxa were generally associated with higher concentrations of contaminants in sediments.

- The relationship between sediment contamination and abundances of several selected benthic taxa was characterized by a response region where abundances were consistently low at high concentrations of contaminants. An apparent threshold in

TABLE 34. CORRESPONDENCE BETWEEN STATIONS HAVING SIGNIFICANT ($P<0.001$) BIOASSAY RESPONSES AND STATIONS HAVING SIGNIFICANT ($P<0.001$) BENTHIC DEPRESSIONS

	Benthic Depression	
Bioassay Response	Yes	No
Yes	25%	0%
No	44%	31%

NOTE: Total no. stations = 16.

the biological response was found for Axinopsida serricata, Euphilomedes spp., Psephidia lordi, Pelecypoda, and Gastropoda in relation to specific concentrations of each of the following chemicals: LPAH, HPAH, naphthalene, 4-methylphenol, retene, phenol, and sulfides. For the other organic compounds evaluated, the number of stations with detected values was too small or the distribution of the data was too skewed to show a strong association with biological variables.

- The abundance of the pollution-tolerant polychaete Capitella capitata displayed a roughly linear increase with sulfide concentration in sediments and no apparent relationship with concentrations of other chemicals or grain size.

- Amphipod mortality was generally high at higher concentrations of 4-methylphenol, retene, TOC, chlorinated phenols, resin acids, and sulfides, but was not clearly related to the other chemical variables evaluated. The high amphipod mortalities found at several stations were not fully explained by the potential relationship between sediment toxicity and grain size.

- Biological effects generally decreased along a spatial gradient from the head of the East Waterway (Station EW-01) to stations southwest of the historical Weyerhaeuser kraft mill site. The concentrations of sulfides and chlorinated phenols/guaiacols followed a similar trend at selected stations where biological variables were measured. Concentrations of some resin acids, 4-methylphenol, and LPAH were relatively low at the head of the East Waterway compared with the next station to the south (Station EW-04), but otherwise corresponded generally to the biological effects data. Although the specific chemical or suite of chemicals responsible for biological effects probably varies among stations, the major biological impacts observed at Stations EW-01, EW-04, and EW-07 are likely related to pulp mill discharges. The observed spatial gradient is probably not representative of fine-scale spatial patterns, since chemical contamination is more complex along a similar transect when data from chemistry only stations are considered.

- Both severe (>40 percent) amphipod mortality and severe (>80 percent) depression of at least one major taxon of infauna were observed at the following highly contaminated sites: Stations EW-01, EW-04, and EW-07. Severe biological effects were found at only one station (i.e., depressions of three major taxa at Stations SD-01) where chemical contamination was relatively low (i.e., all concentrations were below LAET). Sediment structure and physical disturbance due to current scour probably accounts for benthic depressions at Station SD-01.

- The abundances of both indigenous amphipods and gastropods were consistently low at stations with ≥50 percent amphipod mortality in the toxicity bioassay. The abundances of both polychaetes and pelecypods were not clearly related to amphipod mortality.

- Concordance between statistically significant responses in the toxicity bioassay and depressions of infaunal taxa was not substantially greater than that expected by chance alone. This is not surprising given the wide range and levels of contaminants in the Everett Harbor system and the different endpoints measured by these two indicators (i.e., acute mortality of adults of a single species in the bioassay and chronic effects on all life stages of an assemblage of species in the benthic infaunal indices). Moreover, concordance between the bioassay and benthos was found at highly contaminated sites, especially in the East Waterway.

PRIORITIZATION OF PROBLEM AREAS AND CONTAMINANTS

In this section, the selected data for indicators of sediment contamination, toxicity, and biological effects are integrated to evaluate toxic contamination problems in the Everett Harbor system. The approach for the ranking of problem areas was described earlier (see **Decision-Making Framework** in **Methods** section) and is summarized in Figure 3. Based on the significance and magnitude of EAR compiled in the Action Assessment Matrix format, analysis of problem areas and their priority ranking was performed in the following phases:

- **Tier I Problem Definition**--Identification of broad areas that exceeded action-level guidelines (see Table 3) for combined significant elevations of sediment chemistry, fish pathology and bioaccumulation

- **Tier II Problem Definition**--Identification of problem stations that triggered action-level guidelines based on significant EAR and exceedance of a) the 90th percentile concentration or HAET of chemicals in sediments, b) 80 percent depression of any one of four major benthic taxa (Polychaeta, Crustacea, Pelecypoda, or Gastropoda), c) 40 percent mortality in the amphipod bioassay, or d) any combination of the preceding.

Grouping of problem stations into multi-station problem areas was based on chemical distributions (including data from recent historical studies), the nature and proximity of potential sources, and geographic and hydrographic boundaries.

- **Ranking of Problem Sites**--Scoring of problem stations following the criteria in Table 4, and ranking of each multi-station problem area based on the average of the scores for individual stations within the area.

A characterization of each Tier II problem area based on the distributions of potential problem chemicals that exceeded AET is also provided in this section.

IDENTIFICATION OF PROBLEM AREAS

Broad areas of the nearshore Everett Harbor system displayed concentrations of chemical contaminants in sediments above the maximum values for Puget Sound reference areas. Nevertheless, chemical elevations at most stations outside the East Waterway were not highly elevated above reference values. Because neither bioaccumulation nor pathological variables were significantly elevated in the study area ($P>0.001$), Tier I problem evaluation did not result in definition of large-scale problem areas. Areas of potential concern were defined based on exceedance of LAET for at least one chemical in sediments. As shown below, these areas of potential concern are largely contiguous with the problem areas defined in the Tier II analysis.

Information on the significance of EAR for all indicators at each station was compiled in an Action Assessment Matrix. Stations identified as Tier II problem sites (Figure 66) were considered for further priority ranking. A matrix of priority scores for Tier II problem areas and the indicators that exceeded action levels for severe contamination and effects is presented in Appendix I.

The following problem areas containing multiple stations were identified (Figure 66):

- EW (the East Waterway)
- NG (near the Mukilteo sewage discharge, ferry terminal and defense fuel storage depot).

In addition, the following single stations were identified as localized problem areas: ES-03, OG-01, SD-01, SD-03, SR-05, SR-07 (Figure 66).

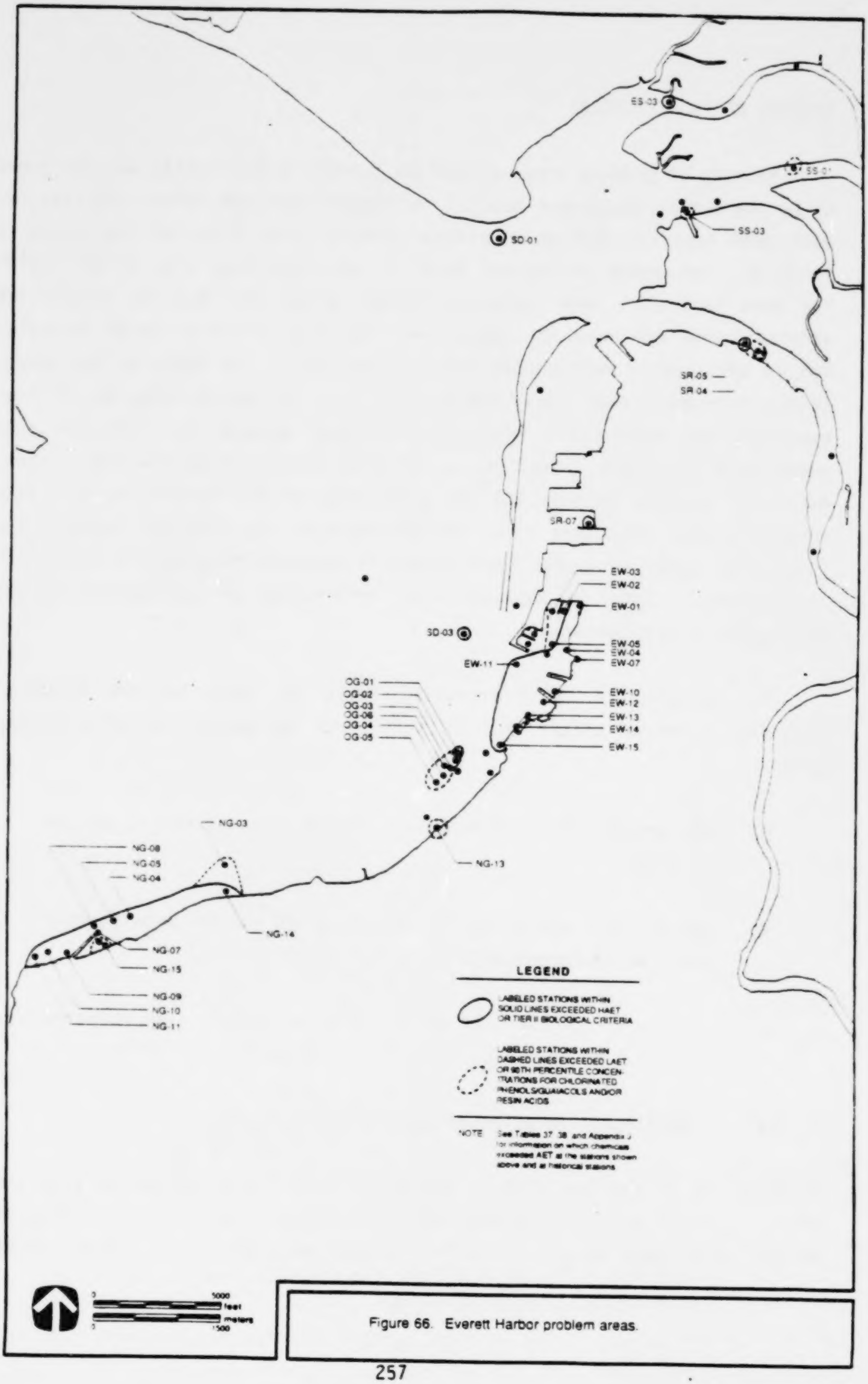

ES-03
SS-01
SS-03
SD-01
SR-05
SR-04
SR-07
EW-03
EW-02
EW-01
SD-03
EW-05
EW-04
EW-07
EW-11
OG-01
OG-02
OG-03
OG-06
OG-04
OG-05
EW-10
EW-12
EW-13
EW-14
EW-15
NG-03
NG-08
NG-05
NG-04
NG-13
NG-14
NG-07
NG-15
NG-09
NG-10
NG-11
LEGEND
LABELED STATIONS WITHIN SOLID LINES EXCEEDED HAET OR TIER II BIOLOGICAL CRITERIA
LABELED STATIONS WITHIN DASHED LINES EXCEEDED LAET OR 90TH PERCENTILE CONCENTRATIONS FOR CHLORINATED PHENOLS/GUAIACOLS AND/OR RESIN ACIDS
NOTE See Tables 37, 38, and Appendix J for information on which chemicals exceeded AET at the stations shown above and at historical stations
0
5000
feet
meters
0
1500

Figure 66. Everett Harbor problem areas.

RANKING OF PROBLEM AREAS

Ranking of problem areas within the Everett Harbor system was performed using the Action Assessment Matrix. Arithmetic mean EAR values compiled for each data type and each multi-station problem area (Tier II) are shown in Table 35. Reference values are shown on the right-hand side of the table. For each indicator, mean reference values across all stations within the reference area are shown for comparison. The original value for an indicator can be obtained by multiplying the EAR reported in the table by the appropriate reference value. Only the original data for the prevalences of liver neoplasms and megalocytic hepatosis are shown because the reference area prevalences were zero, resulting in infinite elevations at the study sites. Note that benthic infauna EAR are calculated as the inverse of the ratio used for other indicators (i.e., as the ratio of the reference value to the study site value) because a toxic effect is expected to produce a depression in abundance. Refer to Appendix I for information on each station in the multi-station problem areas.

For perspective in interpreting Table 35, each of the following represent a severe effect that is sufficient for definition of a problem area:

- >40 percent amphipod mortality, which corresponds to an EAR of >1.8
- ≥80 percent depression in abundance of one or more benthic taxa, which corresponds to an EAR of ≥5
- Exceedance of the HAET or the 90th percentile (for selected chemicals without AET) for sediment chemistry
- Significant elevation of any three indicators.

At least one of the four primary conditions just listed are met by each area shown in Table 35. Significant EAR for sediment chemistry and exceedances of HAET were found in all of the Tier II problem areas except Station SD-01,

TABLE 35. ACTION ASSESSMENT MATRIX OF SEDIMENT CONTAMINATION, TOXICITY, AND BIOLOGICAL EFFECT INDICES FOR EVERETT HARBOR PROBLEM AREAS

Variable	Problem Area Elevations[a]								Reference Value[b]
	East Waterway	Area NG	ES-03	OG-01	SD-01	SD-03	SR-05	SR-07	
Sediment Chemistry									
LPAH	310	31	4.4	21	1.1	9.8	21	12	<41 ppb
HPAH	89	36	3.6	8.4	0.70	3.6	22	17	<79 ppb
4-methylphenol	1,900	200	110	98	0.20	57	150	17	<13 ppb
Phenol	40	24	36	14		3.9	3.6	7.9	<33 ppb
2-methylphenol	40								U 7 ppb
2,4-dimethylphenol	14								U 7 ppb
Benzoic acid	14	5.4	5.2			5.3	6.9	1.4	<150 ppb
Dehydroabietic acid	430				0.50		56		<63 ppb
Benzyl alcohol	17					9.9	4.2		U 10 ppb
PCBs	180	120				3.2			<6 ppb
p,p'-DDT						2.3			U 10 ppb
1,2-dichlorobenzene	20	11							U 3.5 ppb
Copper	26	2.8	3.8	5.4	2.9	8.2	9.0	15	6.37 ppb
Zinc	43	3.0	3.6	4.4	2.7	4.8	5.5	8.1	19 ppb
Sediment Toxicity									
Amphipod mortality	2.9	1.7	0.68		0.68			1.5	22%
Infauna									
Polychaetes	2.3	1.7			160			5.4	1,570/m^2
Gastropods	7.4	0.08			taxon absent			5	50/m^2
Pelecypods	150	0.43			24			5.6	1,560/m^2
Crustaceans	3.6	0.4			5.2			63	1,000/m^2
Fish Pathology									
Neoplasms[c]	1	2.7				1.7			0%
Foci	0.71	1.9				0.49			7.1%
Megalocytic hepatosis[c]	8	2.7				0			0%
Bioaccumulation									
PCBs - English sole	3.2	3.8				2.8			8.3 ppb
PCBs - Dungeness crab	2.1	2.8				0.70			5.0 ppb

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[a] Boxed numbers represent elevations of chemical concentrations that exceed all Puget Sound reference area values, and statistically significant ($P<0.001$) toxicity and biological effects at one or more stations compared with reference conditions in Port Susan. Significance tests were not performed on the bioaccumulation data (see **Results**). Chemicals shown in the table had concentrations exceeding HAET or EAR >1,000. The "U" qualifier indicates the chemical was undetected and the detection limit is shown. The "<" qualifier indicates the chemical was undetected at one or more stations. The detection limit is used in the calculations. Infauna EAR are based on the elevation in biological effects represented by reductions in infaunal abundances relative to reference conditions. EAR for all other variables reflect an increase in the value of the variable at Everett Harbor compared with reference conditions. Blank spaces in sediment chemistry columns indicate that the chemical was undetected throughout the problem area.

[b] EAR values shown for each area are based on Carr Inlet reference values for sediment chemistry and on Port Susan (1986) reference values for biological variables.

[c] Prevalences of neoplasms and megalocytic hepatosis at each problem area are shown in table instead of EAR because the reference values were 0%.

which exhibited severe depressions in the abundances of major taxa of benthic infauna, but not significant ($P<0.001$) amphipod mortality. Chemicals that exceeded AET at each station are discussed in the next section (see **Chemical Characterization of Problem Areas**).

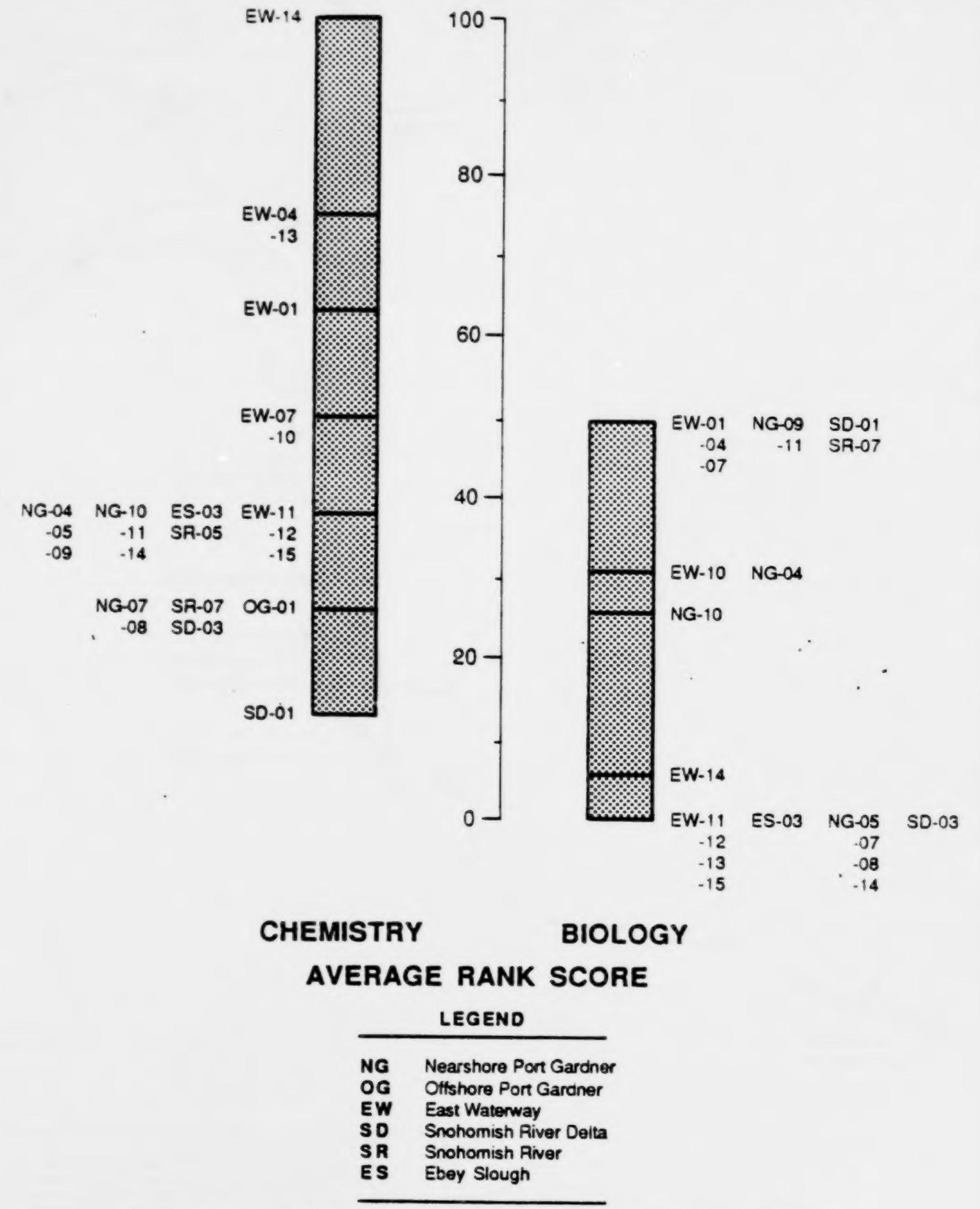
Total scores for sediment chemistry and biological effects were determined separately for each station. The ranking criteria presented in Table 4 were applied to the Action Assessment Matrix for single stations (Appendix I). The score for each multi-station area was calculated as the average of the scores for individual stations within the area (for details, see **Decision-Making Framework** in **Methods** section). Normalized scores for the Tier II problem areas and single stations are presented in Figure 67.

Of the two multi-station problem areas, the East Waterway ranked highest, with average scores of 58 percent for chemistry and 21 percent for biology. The multi-station problem area near Mukilteo received average scores of 34 percent for chemistry and 20 percent for biology. Biological scores varied greatly among stations within both of these areas. Sediment chemistry scores were heterogeneous within the East Waterway, but not within the NG problem area near Mukilteo.

Ten stations scored ≥50 percent based on either sediment chemistry or biological effects (Figures 67 and 68). Of the 10 highest priority stations, three scored ≥50 percent for both sediment chemistry and biological effects:

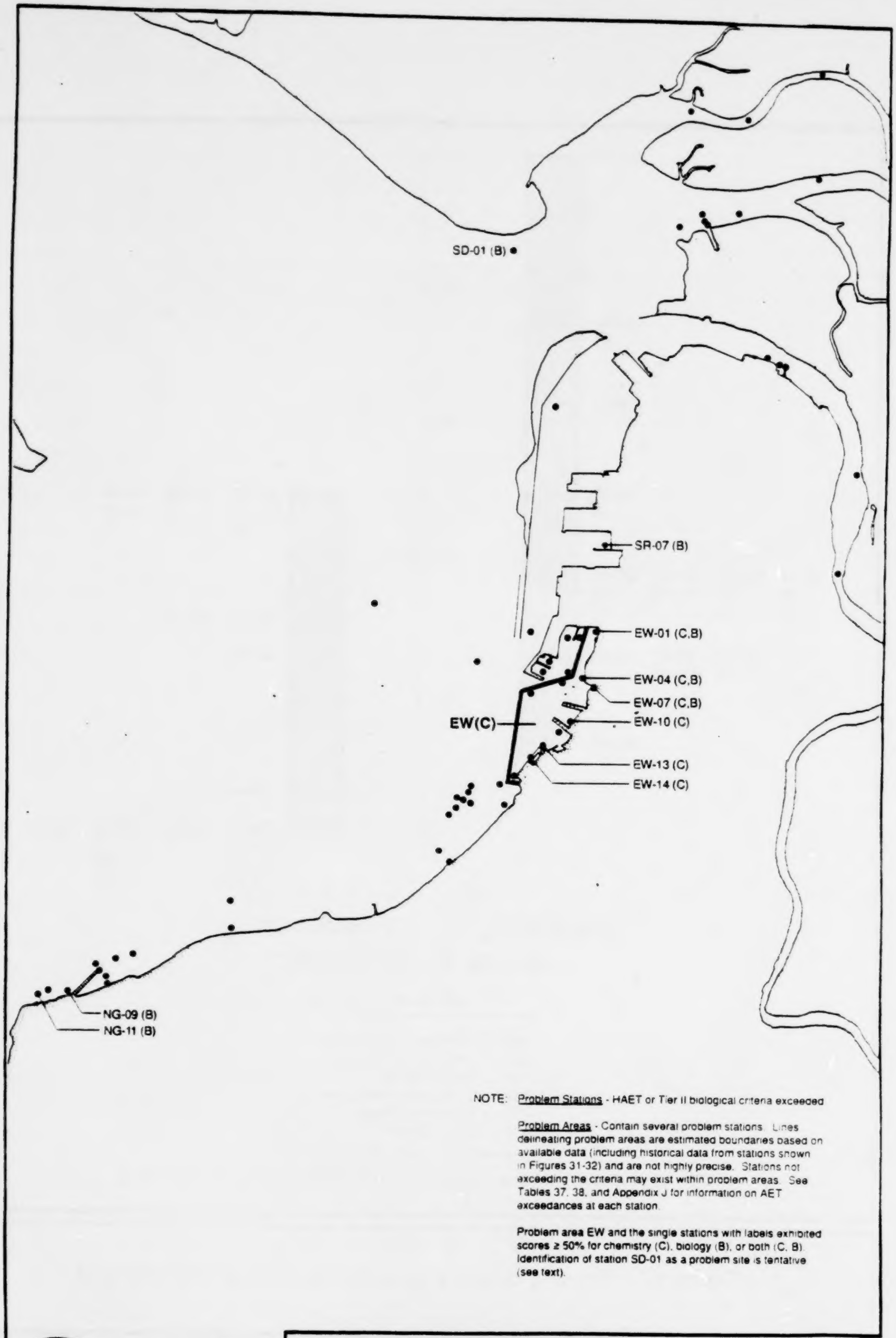
- Station EW-01
- Station EW-04
- Station EW-07.

Stations EW-10, EW-13, and EW-14 scored ≥50 percent based on chemical variables alone. Stations NG-09, NG-11, SD-01, and SR-07 scored ≥50 percent based on biological variables alone. Station SD-01 received a high score for biology because benthic infauna were apparently impacted. However, swift currents within the delta channel where this station was located (as



NOTE: Limited biological data were available for most stations (see Appendix I).

Figure 67. Ranking of single stations classified as problem sites.


SD-01 (B)
SR-07 (B)
EW-01 (C,B)
EW-04 (C,B)
EW-07 (C,B)
EW(C)
EW-10 (C)
EW-13 (C)
EW-14 (C)
NG-09 (B)
NG-11 (B)
0
5000
feet
meters
0
1500

NOTE: Problem Stations - HAET or Tier II biological criteria exceeded

Problem Areas - Contain several problem stations. Lines delineating problem areas are estimated boundaries based on available data (including historical data from stations shown in Figures 31-32) and are not highly precise. Stations not exceeding the criteria may exist within problem areas. See Tables 37, 38, and Appendix J for information on AET exceedances at each station.

Problem area EW and the single stations with labels exhibited scores ≥ 50% for chemistry (C), biology (B), or both (C, B). Identification of station SD-01 as a problem site is tentative (see text).

Figure 68. Highest priority problem sites.

indicated by bathymetry and coarseness of the sediments) may be responsible for disturbance of the benthic community. Because bioassay mortality was low (15 percent) at Station SD-01, and because species composition of benthic infauna indicated an absence of impacts attributable to toxic chemicals, the designation of Station SD-01 as a problem area should be considered tentative. Sediment texture, hypoxia, or high sulfides concentrations at Station SR-07 may have contributed to the severe depressions in the abundances of infaunal taxa at that site. Station EW-14 received the maximum possible score of 100 percent for chemistry, but scored very low (6 percent) for biology. Despite the lack of statistical significance in some EAR for biological variables, increased toxicity of sediments to amphipods and effects on benthic infauna at Station EW-14 were apparent based on comparisons with adjacent stations (see Figure 63).

CHEMICAL CHARACTERIZATION OF PROBLEM AREAS

In this section, the Tier II multiple-station and single-station problem areas listed above are characterized with regard to the distributions of selected problem chemicals (Table 36) and other chemicals of concern. To facilitate analysis by the Everett Harbor Work Group, a description is provided of the chemicals at notable stations within each problem area. Detailed tables of AET exceedances (including the factor by which AET were exceeded) are included in Appendix J, and more detailed descriptions of chemical distributions are presented in the **Results** section. The following points should be considered regarding the application of AET to chemical data in this study:

- AET values have not been established for all chemicals measured in the present study (most notably, resin acids and chlorinated phenols/guaiacols). For this reason, another criterion (EAR >1,000) was used in addition to AET to establish problem chemicals. Also, 90th percentile concentrations of chlorinated phenols/guaiacols and resin acids were used to designate lower priority problem stations.

TABLE 36. EVERETT HARBOR PROBLEM CHEMICALS

LPAH[a]
2-methylnaphthalene
dibenzofuran
dibenzothiophene
4-methylphenol
phenol
2-methylphenol
2,4-dimethylphenol
benzoic acid
dehydroabietic acid[b]
benzyl alcohol
PCBs
p,p'-DDT
1,2-dichlorobenzene
copper
zinc

HPAH[c,d]
butyl benzyl phthalate[d]
N-nitrosodiphenylamine[d]
arsenic[d]
cadmium[d]
lead[d]
mercury[d]

[a] The term LPAH represents the following chemicals: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene.

[b] Established as a problem chemical based upon EAR>1,000. No AET is available for dehydroabietic acid.

[c] The term HPAH represents the following chemicals: fluoranthene, pyrene, benzo(a)anthracene, chrysene, total benzofluoranthenes, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene.

[d] This chemical exceeded the LAET but not the HAET. Other chemicals in this table exceeded the HAET at least one time (except dehydroabietic acid, footnote b).

- AET for antimony, chromium, nickel, beryllium, and thallium were not used to determine problem stations in this study. The AET for antimony and chromium were not used because of the likelihood that analytical methods used to generate AET for these chemicals are not directly comparable to the methods used in the present study (see **Chemistry, Quality Assurance/Quality Control Results** in **Methods** section). The AET for nickel was not used because the range of nickel concentrations in the database used to generate existing Puget Sound AET is relatively limited. Beryllium and thallium were excluded for similar reasons; the exclusion of these two chemicals applies only to historical data, as they were not measured in the present study.

East Waterway Problem Area

Sediment contamination in this depositional area is extreme and complex, and appears strongly related to pulp industry discharges. Additional sources (e.g., CSOs and storm drains) may be important for some chemicals. The East Waterway problem area contained the highest sediment concentration of virtually every chemical measured in this study, including phenolic compounds (e.g., alkyl-substituted phenols, chlorinated phenols, chlorinated guaiacols), resin acids (both chlorinated and unchlorinated), PAH, PCBs, and most metals. The most severe contamination was observed along the east shore of the waterway (near potential sources), although the area near the west shore of the waterway was less well characterized for certain organic compounds.

Although many chemicals exceeded HAET in the East Waterway problem area, 4-methylphenol and LPAH concentrations exceeded HAET most frequently (Table 37) and were important in defining problem area boundaries. 4-Methylphenol concentrations maximized at Station EW-07 (98,000 ug/kg DW; EAR=7,500). Concentrations decreased along the east shore moving away from Station EW-07, but nonetheless exceeded an EAR of 1,000 at Stations EW-04, EW-10, EW-13, and EW-14 (concentrations ranged between 15,000 and 35,000 ug/kg DW at these stations). LPAH concentrations in the East

TABLE 37. EAST WATERWAY PROBLEM AREA[a]

Station	HAET Exceedances[b]															LAET Exceedances[d]
	LPAH	HPAH	4MEPHNL	PHNL	2MEPHNL	2,4-MEPHNL	BNZACID	BNZOH	PCBS	1,2DICLBNZ	CU	ZN	TOC	DHA[c]	TOTXYLENE	
EW-01			X	X												BUTBNZPH, NNP [24CLPHNL, 245CLPHNL, 246CLPHNL, 2346CLPHNL, 345TCG, 456TCG, TETCG, SANDARACO]
BPS30[e]	X	X														PCBS, ZN
E-04[f]	X			X												HPAH, PCBS, ZN
EW-04	X		X	X	X	X		X	X	X			X	X		HPAH [2CLPHNL, 24CLPHNL, 2346CLPHNL, PCP, ABIETIC, ISOPIMARIC, SANDARACO, 12CLDHA, 14CLDHA]
EW-07	X		X		X	X										PHNL [ISOPIMARIC, 12CLDHA]
PS05[g]	X	X													X	ZN
BPS29[e]	X															HPAH, PCBS
PS06[g]	X															HPAH
EW-10			X	X												LPAH, HPAH, HG
EW-11			X													BNZOH, PHNL
EW-12			X													
BPS28[e]	X															HPAH, PCBS
EDS-4[h]		X											X			PCBS
A4[i]													X			
EW-13	X		X										X	X		PHNL, ZN, HPAH [24CLPHNL, ABIETIC, ISOPIMARIC]
EW-14	X		X	X			X				X	X				HPAH, AS, CD, PB, HG
EW-15	X		X													

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[a] Chemical codes used in this table:

LPAH - Signifies AET exceedances for the sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene, or any of these compounds individually. To simplify the presentation of AET exceedances in this table, exceedances of AET for 2-methylnaphthalene, dibenzofuran, and dibenzothiophene are included under LPAH. These compounds covaried with LPAH but are not included in LPAH sums.

HPAH - Signifies AET exceedances for the sum of fluoranthene, pyrene, benzo(a)anthracene, chrysene, total benzofluoranthenes, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene, or of any of these compounds individually.

4MEPHNL - 4-methylphenol
PHNL - phenol
2MEPHNL - 2-methylphenol
2,4-MEPHNL - 2,4-dimethylphenol
BNZACID - benzoic acid
BNZOH - benzyl alcohol
PCBS - polychlorinated biphenyls

2CLPHNL - 2-chlorophenol
24CLPHNL - 2,4-dichlorophenol
245CLPHNL - 2,4,5-trichlorophenol
246CLPHNL - 2,4,6-trichlorophenol
2346CLPHNL - 2,3,4,6-tetrachlorophenol
PCP - pentachlorophenol
345TCG - 3,4,5-trichloroguaiacol

TABLE 37. (Continued)

1,2DICLBNZ - 1,2-dichlorobenzene
CU - copper
ZN - zinc
TOC - total organic carbon
DHA - dehydroabietic acid
TOTXYLENE - total xylene

456TCG - 4,5,6-trichloroguaiacol
TETCG - tetrachloroguaiacol
ABIETIC - abietic acid
ISOPIMARIC - isopimaric acid
SANDARACO - sandaracopimaric acid
12CLDHA - 12-chlorodehydroabietic acid
14CLDHA - 14-chlorodehydroabietic acid
BUTBNZPH - butyl benzyl phthalate
NNP - N-nitrosodiphenylamine
HG - mercury
AS - arsenic
CD - cadmium
PB - lead

[b] Chemicals exceeding HAET for Puget Sound. More detailed information on exceedances is presented in Appendix J.

[c] DHA has no established AET, but was considered a problem chemical because concentrations exceeded EAR of 1,000. Stations with EAR >1,000 are noted in this table.

[d] Chemicals exceeding LAET for Puget Sound. More detailed information on exceedances is presented in Appendix J. Chemicals shown in brackets exceeded 90th-percentile concentrations for chlorinated phenols/guaiacols and/or resin acids.

[e] Crecelius et al. (1984).

[f] Battelle (1986).

[g] Storer and Arsenault (1987).

[h] U.S. Army COE (1985).

[i] Anderson and Crecelius (1985).

Waterway problem area were somewhat patchy overall, but the highest concentrations occurred near Stations EW-04 and EW-07 (LPAH concentrations in this area ranged from 17,000 to 100,000 ug/kg DW, including historical stations) and at Stations EW-13 and EW-14. Naphthalene was typically the predominant PAH in the East Waterway and, like 4-methylphenol, occurred at its maximum concentration at Station EW-07 (17,000 ug/kg DW; EAR=3,000).

Many compounds strongly related to the pulp industry were observed at elevated concentrations in the East Waterway problem area, especially at Station EW-01 (at the head of the waterway), Station EW-04, and Station EW-13. Relationships between certain observed chemicals and pulp industry activities are discussed in the Results section. Stations EW-04 and EW-13 had the highest observed concentrations of DHA and abietic acid, the most prevalent resin acids in the study (the highest concentrations of both resin acids were between 80,000 and 100,000 ug/kg DW). Distribution patterns of resin acids suggested that contamination at Stations EW-04 and EW-13 derived from distinct sources of a similar nature; however, chlorinated compounds were more prevalent at Station EW-04 than at Station EW-13. Chlorinated resin acid concentrations maximized at Station EW-04, as did 2-chlorophenol, pentachlorophenol, 2-methylphenol, 2,4-dimethylphenol, most TIO compounds (including compounds potentially related to resin acids, such as retene and a diterpenoid hydrocarbon), and a number of other compounds (see Table 17). Chlorinated phenols (dichloro- through tetrachloro-) and chlorinated guaiacols had pronounced concentration maxima at the head of the waterway, at Stations EW-01 and EW-02. Stations EW-02 and EW-03 (at the head of the waterway) and EW-05 are not strictly included in the problem area (see Figure 66), but are lower priority problem stations based upon the exceedances of 90th percentile concentrations for various chlorinated phenols.

The contaminant assemblage at Station EW-14 was unique in the problem area, as HAET were exceeded for copper (1,010 mg/kg DW), zinc (5,910 mg/kg DW), and benzoic acid (5,900 ug/kg DW), as well as other problem chemicals that were relatively widespread in the problem area (e.g., LPAH and 4-methylphenol). Copper and zinc concentrations were over an order of magnitude lower at other East Waterway stations.

Distributions of conventional sediment variables were consistent with distributions of organic compounds that are likely related to pulp mill activities. For example, TOC content was elevated in the East Waterway overall, but particularly at Stations EW-04 and EW-13 (from 20 to 30 percent TOC). Sulfides were highly concentrated (>7,000 mg/kg DW) at the head of the waterway and at Station EW-04.

Problem Area NG

Problem Area NG was most extensively contaminated with polar organic compounds (i.e., 4-methylphenol, benzoic acid, and to a lesser extent, phenol), although relatively high concentrations of PAH and PCBs were observed in localized areas (Table 38). Overall, distributions of different contaminants were not consistent in this problem area. Of the problem chemicals in this area, 4-methylphenol most often exceeded HAET [Table 38; Stations NG-04, NG-05, NG-09, NG-10, NG-11, and NG-14 (intertidal)]. Station NG-05 had the highest 4-methylphenol concentration in this area (9,700 ug/kg DW), with concentrations between 1,600 and 2,400 ug/kg DW at the other stations mentioned above. Concentration gradients of 4-methylphenol were not apparent and the stations with the highest concentrations were not all contiguous. For example, Stations NG-05 and NG-09 (2,400 to 9,700 ug/kg DW) were separated by a transect of four stations all with concentrations <1,000 ug/kg DW. However, 4-methylphenol distributions between the East Waterway and this problem area suggest a local source (or sources) rather than transport from the more highly contaminated East Waterway.

An area near the Mukilteo wastewater treatment plant and west of the Mukilteo fuel depot had relatively high concentrations of several contaminants in addition to 4-methylphenol (particularly Station NG-09 and historical Station MUK-B). PAH concentrations were particularly elevated at historical Station MUK-B (LPAH=11,000 ug/kg DW; HPAH=15,000 ug/kg DW). PAH concentrations at Station NG-09 and NG-11 were within a factor of 2-3 of these values, whereas PAH concentrations at NG stations east of NG-09 were over 30 times lower. The PCB concentration at Station NG-09 (5,500 ug/kg DW)

TABLE 38. NEARSHORE PORT GARDNER (NG) PROBLEM AREA[a]

	HAET Exceedances[b]						
Station	LPAH	HPAH	4MEPHNL	PHNL	BNZACID	PCBS	LAET Exceedances[c]
NG-14			X				PHNL
NG-04			X				
NG-05			X		X		
NG-07					X		
NG-08					X		4MEPHNL
NG-09			X	X		X	LPAH
MUK-B[d]	X						HPAH, PCBS
NG-10			X				PHNL
NG-11			X				PHNL, LPAH

[a] Chemical codes used in this table:

LPAH -	Signifies AET exceedances for the sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene, or any of these compounds individually. To simplify the presentation of AET exceedances in this table, exceedances of AET for 2-methylnaphthalene are included under LPAH. This compound covaried with LPAH but is not included in LPAH sums.
HPAH -	Signifies AET exceedances for the sum of fluoranthene, pyrene, benzo(a)anthracene, chrysene, total benzofluoranthenes, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene, or of any of these compounds individually.
4MEPHNL -	4-methylphenol.
PHNL -	Phenol.
BNZACID -	Benzoic acid.
PCBS -	Polychorinated biphenyls.

[b] Chemicals exceeding HAET for Puget Sound. More detailed information on exceedances is presented in Appendix J.

[c] Chemicals exceeding LAET for Puget Sound. More detailed information on exceedances is presented in Appendix J.

[d] Malins et al. (1985).

exceeded the HAET, although nearby stations had concentrations (or detection limits) that were over 25 times lower. The HAET for phenol was also exceeded at Station NG-09 (2,100 ug/kg DW). Station NG-09 was also somewhat enriched in TOC relative to other NG stations (3.8 percent TOC vs. <0.8 percent at other NG stations).

Benzoic acid concentrations exceeded HAET at three stations offshore from the Mukilteo fuel depot (Station NG-05, NG-07, and NG-08; 1,300 to 2,100 ug/kg DW). A transect of stations was sampled in this area [moving away from shore: Station NG-15 (intertidal), Station NG-06, Station NG-07, and Station NG-08]. Notably, benzoic acid concentrations nearer shore (10 to 80 ug/kg DW) were considerably lower than at Stations NG-07 and NG-08 farther offshore.

Problem Area OG-01

The sole problem chemical at Station OG-01 was 4-methylphenol (1,300 ug/kg DW). Most other OG stations had similar 4-methylphenol concentrations that were slightly below the HAET but above the LAET (Stations OG-02 to OG-06; 720 to 1,200 ug/kg DW). Overall, this area was characterized by very consistent concentrations of a number of chemicals, including 4-methylphenol, PAH (dominated by naphthalene, as in the East Waterway), resin acids (unchlorinated and chlorinated), and a cymene isomer. These chemicals have varying degrees of association with the pulp industry (e.g., of this group, resin acids are most strongly associated with this industry). Although such chemicals could have been transported from the East Waterway, several lines of evidence suggest that contamination derives from the OG area itself (e.g., from the pulp industry discharge near Station OG-03): (1) concentrations are consistent in the OG area, and do not clearly decrease with distance from the East Waterway; (2) examination of chemical contamination along a transect from Station EW-15 (at the mouth of the East Waterway) to Station NG-01 (near Station EW-15) to Station OG-01 (further from Station EW-15) reveals that concentrations of several diagnostic compounds (4-methylphenol, naphthalene, a cymene isomer, the diterpenoid hydrocarbon TIO) decrease from Station EW-15 to NG-01 and then increase at Station OG-01 (note that resin acids were not tested at

Stations NG-01 and OG-01); and (3) contamination patterns within the East Waterway (i.e., prominent concentration maxima for certain chemicals) do not suggest the presence of strong advection processes.

Problem Area SR-05

Station SR-05 was located on the Snohomish River near a kraft mill facility. Benzoic acid and 4-methylphenol exceeded HAET at this station (1,000 and 2,000 ug/kg DW, respectively). The 4-methylphenol concentration at adjacent Station SR-04 exceeded the LAET (980 ug/kg DW). A number of resin acids were detected at Station SR-05, including DHA and abietic acid (3,500 and 2,300 ug/kg DW). Concentrations of these resin acids decreased moving upriver from Station SR-05 to SR-03, and were roughly five times lower at Station SR-04 than at Station SR-05 (although these two stations had similar sediment texture). A chlorinated resin acid (12-chlorodehydroabietic acid) was detected below nominal detection limits at Station SR-04 (63 ug/kg DW).

Problem Area SD-03

Station SD-03, located on the Snohomish River delta near the East Waterway, had concentrations of three chemicals exceeding HAET: benzoic acid (770 ug/kg DW), benzyl alcohol (99 ug/kg DW), and p,p'-DDT (23 ug/kg DW). The 4-methylphenol concentration at this station exceeded LAET (760 ug/kg DW).

Problem Area ES-03

Benzoic acid and 4-methylphenol exceeded HAET at this Ebey Slough station (760 and 1,400 ug/kg DW, respectively). The LAET for phenol was also exceeded at Station ES-03 (1,200 ug/kg DW, blank-corrected). Concentrations of benzoic acid and 4-methylphenol at Station ES-02 (upriver) were at least 30 times lower than at Station ES-03.

Problem Area SD-01

Station SD-01 on the Snohomish River delta did not have any chemicals exceeding AET; it was designated as a problem station based upon benthic effects that exceeded action-level guidelines. EAR for Everett Harbor problem chemicals did not exceed four at this station. Sediment at this station was predominantly coarse-grained (<5 percent fine-grained material).

Problem Area SR-07

Station SR-07, located near the Everett marina on the Snohomish River, was also designated as a problem station based upon benthic effects that exceeded action-level guidelines; no AET were exceeded at this station. However, TBT was reported at 0.093 mg/kg DW at this station, and the sediment was very fine-grained (96 percent fine-grained material) and had a high sulfide concentration (600 mg/kg DW).

SUMMARY

Identification of Problem Areas

- Broad areas of nearshore Everett Harbor and the lower Snohomish River displayed low elevations of chemical concentrations in sediments relative to Puget Sound reference areas. Because the area-wide indicators related to bioaccumulation and pathology were not significantly elevated ($P>0.001$), large-scale problem areas were not identified throughout most of the study area.

- Specific problem areas were defined on a finer spatial scale (Tier II). Twenty-three stations were designated as problems. Seventeen of these stations were grouped into the following multi-station problem areas: East Waterway, and the nearshore area from Elliott Point in Mukilteo east to Powdermill Gulch.

Ranking of Problem Areas

- Ranking of Tier II problem areas showed that the East Waterway was a higher priority than the Nearshore Port Gardner problem area.

- Ten stations were identified as the highest priority sites. Of these, Stations EW-01, EW-04, and EW-07 scored ≥50 percent for both chemical and biological variables.

Characterization of Problem Areas

East Waterway Problem Area--

- Sediment contamination in this depositional area is extreme and complex, and appears strongly related to pulp industry discharges, although additional sources may be important for some chemicals. The East Waterway problem area contained the maximum sediment concentration of virtually every chemical measured in this study, although maximum concentrations of different chemicals occurred at different stations: Station EW-01 (chlorinated guaiacols and dichloro- through tetrachlorophenols); Station EW-04 (certain chlorinated and unchlorinated resin acids, some alkyl-substituted and chlorinated phenols, most TIO compounds, and PCBs; this station had the largest number of exceedances of HAET and 90th percentile concentrations in the study); Station EW-07 (4-methylphenol and naphthalene); Station EW-13 (certain unchlorinated resin acids); and Station EW-14 (most PAH, benzoic acid, zinc, copper, arsenic, and other metals).

- The relationship between pulp industry activities and sediment contamination was suggested by several lines of chemical evidence, including distributions of distinctive geochemical tracers (e.g., chlorinated resin acids and chlorinated guaiacols) and related compounds (e.g., unchlorinated resin acids, chlorinated phenols, retene, diterpenoid hydrocarbons), as well as distributions of other compounds potentially related to the pulp industry [e.g., 4-methylphenol and naphthalene; refer to Tetra Tech (1985a) for a discussion of the problem area at the mouth of St. Paul Waterway in Commencement Bay, WA, where these chemicals were also associated with a pulp mill discharge] and TOC and sulfides distributions.

- Significant depressions in the abundances of benthic infaunal taxa were found at all six stations sampled in the East Waterway ($P \leq 0.001$). Abundances of three of the four major taxa analyzed were significantly reduced at Stations EW-01 and EW-07. Significant sediment toxicity to amphipods was found at three of the six stations sampled in the East Waterway (Stations EW-01, EW-04, and EW-07; $P \leq 0.001$). The mean amphipod mortality for all six stations was 2.9 times the mean mortality at the Port Susan stations.

Nearshore Port Gardner Problem Area--

- The Nearshore Port Gardner problem area was primarily contaminated with polar organic compounds (i.e., 4-methylphenol, benzoic acid, and to a lesser extent, phenol), although relatively high concentrations of PAH and PCBs were observed in localized areas. Overall, distributions of different problem chemicals were not consistent in this area. Of the problem chemicals in this area, 4-methylphenol most often exceeded HAET. Based upon observed distributions, 4-methylphenol contamination in this area probably derived from undetermined local sources rather than transport from the East Waterway.

- In the Nearshore Port Gardner problem area, a significant depression in the abundance of benthic taxa was found only at Station NG-04 (Polychaeta; $P \leq 0.001$). Mean mortality in the amphipod bioassay was 100 percent at Station NG-04 ($P \leq 0.001$). For Problem Area NG as a whole, the mean amphipod mortality was approximately 1.7 times the reference value.

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Puget Sound Estuary Program

EVERETT HARBOR ACTION PROGRAM:

Analysis of Toxic Problem Areas

TC-3338-26
FINAL REPORT
APPENDICES

September 1988

Prepared by
PTI Environmental Services
and
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Prepared for
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Region X - Office of Puget Sound
Seattle, Washington

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for

U.S. Environmental Protection Agency
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APPENDIX A

EVERETT HARBOR STATION LOCATIONS

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TABLE A-1. EVERETT HARBOR SEDIMENT CHEMISTRY STATION LOCATIONS, DEPTHS, AND DESCRIPTIONS

Station	East coord.	North coord.	Depth MLLW (m)	Description
ES-01	1669900	385010	2.5	Ebey Slough, peak of second bend from mouth
ES-02	1667110	383220	7.7	Ebey Slough, peak of first bend from mouth
ES-03	1664950	383560	0.0	Ebey Slough, mouth
EW-01	1661480	363720	5.1	NE corner of East Waterway, ~150' W of E bank, 150' S of N bank
EW-02	1660580	363720	11.2	North end of East Waterway
EW-03	1660240	363790	9.5	NW corner of East Waterway, just inside pier, between pier & shore
EW-04	1660780	362010	8.7	Off Scott diffuser under pier,~300' from south end of pier
EW-05	1660130	362280	10.5	Center of East Waterway; .17nmi to NW corner of pier 3
EW-06	1659480	362630	7.5	Between piers, northern gap; West side of East Waterway
EW-07	1661100	361610	3.7	Between piers, N-Scott, S-Dunlap, due south of red shed, Scott C1
EW-08	1659960	361840	8.9	Center of mouth of East Waterway
EW-09	1659220	362250	6.8	Between Pier B and pier south of Pier B
EW-10	1660250	360320	9.1	Near head of slip between piers 1 & 3, East Waterway
EW-11	1658770	361420	8.7	Due S of end of jetty, entrance to East Waterway, in line with Pier 3
EW-12	1659800	359910	4.7	South of pier 1, between pier & dolphins, between shore & end of pier
EW-13	1659170	359400	8.2	NW corner of Weyerhaeuser pier (NE corner of Ocean Odyssey)
EW-14	1658710	358940	9.8	Weyerhaeuser pier near SE corner of Ocean Odyssey, W off pump
EW-15	1658100	358250	12.4	S end of Weyerhaeuser pier, mouth of East Waterway,~20' off pier face
NG-01	1657500	357950	8.1	Off Pigeon Creek #1, nearly due west of sign for pipe outfall
NG-02	1655158	355375	8.6	Off Pigeon Creek #2, ~100m directly offshore pipe drains
NG-03	1647260	353600	8.2	Off Powder Mill Gulch,~1000m directly offshore discharge pipes
NG-04	1643480	351600	6.9	Off small boat launch east of Mukilteo fuel depot
NG-05	1642840	351420	8.3	NW end Mukilteo fuel depot, just east of tip of fuel dock
NG-06	1642220	350580	10.2	Mukilteo fuel depot, directly off 4th tank from E end of series
NG-07	1642220	351000	14.3	End of fuel dock at Mukilteo, mid pier-face, about 60' from end
NG-08	1642060	351260	46.4	NW pier off oil tanks
NG-09	1641560	350560	10.5	Near fuel dock (southwestern corner)
NG-10	1640200	350240	9.0	~500' offshore pier at NMFS Mukilteo lab
NG-11	1639810	350140	8.1	West of ferry dock, Mukilteo
NG-12	1657700	357200		Pigeon Creek #1 outfall at island in center of water.
NG-13	1655580	355000		West of Pigeon Creek #2 outfall
NG-14	1647260	352570		Powder Mill Gulch, 50' from outfall, 20' west of creek
NG-15	1642380	350410		Mukilteo ferry terminal/oil tanks, west of Japanese Gulch
OG-01	1656450	357800	82.8	Scott deepwater outfall, across from Weyerhaeuser sulfite mill
OG-02	1656340	357620	85.2	Scott deepwater outfall 2, across from Weyerhaeuser sulfite mill
OG-03	1656110	357300	83.7	Scott deepwater outfall 3, across from Weyerhaeuser sulfite mill
OG-04	1655840	357020	95.3	Scott deepwater outfall 4, across from Weyerhaeuser sulfite mill
OG-05	1655600	356790	91.1	Scott deepwater outfall 5, across from Weyerhaeuser sulfite mill
OG-06	1655860	357410	101.0	Scott deepwater outfall 6, across from Weyerhaeuser sulfite mill
OG-07	1656390	357210	49.6	Scott deepwater outfall 7, across from Weyerhaeuser sulfite mill
PS-02	1608440	418370	7.9	Port Susan 2.8 nmi to Kayak Point
PS-03	1614180	411060	9.1	mid-Port Susan, 2.24 nmi to Kayak Point
PS-04	1619520	405050	8.7	S Port Susan, off houses on S end beach, between bulkheads on beach
SD-01	1658200	378340	4.2	Snohomish Delta, W of Priest Point, S of where spit joins bluff
SD-02	1652820	364922	9.6	Snohomish Delta, SW of Jetty Island, NE of buoy
SD-03	1656710	362650	9.5	Snohomish Delta, slightly SW of Southern tip of Jetty Island
SR-01	1670350	365850	6.8	Snohomish River near I-5
SR-02	1671130	369590	1.8	Snohomish River, east side of little island near Everett Lagoon
SR-03	1668440	373760	7.7	Snohomish River, near Rt. 529
SR-04	1668200	373840	3.2	Snohomish River, near railroad bridge
SR-05	1667760	374090	2.2	Snohomish River, below railroad bridge, off
SR-06	1659750	372320	3.9	Snohomish River/Port Gardner, near Jetty Isl, inside S bend in Jetty
SR-07	1661590	367040	1.0	N corner of Everett Marina ~80' offshore, next to large shed
SR-08	1658760	363750	10.9	Mouth of Snohomish River about 2/3 of way to Jetty Island
SS-01	1669780	380990	3.5	Steamboat Slough, near drawbridges
SS-02	1666710	379650	1.5	Steamboat Slough, off Weyerhaeuser Kraft mill ponds
SS-03	1665540	379250	0.8	Steamboat Slough, off inlet toward Smith Island
SS-04	1665430	379440	2.8	Steamboat Slough, across from inlet toward Smith Island, midstream
SS-05	1665380	379700	1.2	Steamboat Slough, across from inlet toward Smith Island, breakwater
SS-06	1664490	379200	1.3	Steamboat Slough, at mouth near left bank

APPENDIX B

CHEMICAL AND PHYSICAL DATA COLLECTED DURING THE EVERETT HARBOR ACTION PROGRAM

TABLES

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CHEMICAL AND PHYSICAL DATA COLLECTED DURING THE EVERETT HARBOR ACTION PROGRAM

Chemical and physical data collected in support of the Everett Harbor Action Program during September/October 1985 are presented in the following appendix. Data qualifiers were used to describe, clarify, or explain data values. A complete list of data qualifiers used in the Everett Harbor Action Program is provided below:

- U = The compound or element was not detected at the detection limit shown.

- E = The reported concentration is an estimate. The estimated qualifier was assigned for a variety of reasons including exceedance of control limits for calibration, precision, accuracy, and holding times. Data qualified as estimates are acceptable but have a greater uncertainty associated with them than data that are not qualified.

- B = Concentration was corrected for blank contribution. Blank contribution was greater than or equal to the sample value, therefore the reported value is the detection limit.

- Z = Concentration was corrected for blank contribution. Value still exceeds the detection limit.

- X = This qualifier was assigned if the labeled internal standard recovery reported by the laboratory was less than 10 percent.

- L = This qualifier indicates that the value is less than the maximum shown. An "L" qualifier was applied to a group sum

TABLE B-1. CONCENTRATIONS (MG/KG DRY WEIGHT) OF METALS IN EVERETT HARBOR SEDIMENTS

Station	Sampling Date	Rep	Antimony	Arsenic	Cadmium	Chromium	Copper	Iron
ES-01	10/06/86		E11.9	19.7	0.18	98	26.6	29300
ES-02	10/06/86		E3.37	9.7	0.086	99	25.3	27600
ES-03	10/06/86		E2.91	9.8	0.14	153	24.3	29500
EW-01	10/07/86		E6.30	15.7	4.62	94	84.6	27700
EW-04	09/30/86		E7.75	13.9	2.68	68	63.6	16600
EW-07	09/30/86	1	E17.4	20.1	1.41	102	68.2	28300
EW-07	09/30/86	2	E46.7	19.3	1.67	132	77.9	34200
EW-07	09/30/86	3	E16.1	22.9	1.35	115	67.4	29700
EW-07	09/30/86	Mean	E26.7	20.8	1.48	116	71.2	30700
EW-10	10/01/86		E7.92	17.0	2.73	102	74.7	31200
EW-11	09/30/86		E4.55	17.0	1.67	96	62.0	34200
EW-12	10/01/86		E2.33	6.3	0.20	61	17.6	18700
EW-13	10/01/86		E13.6	26.9	1.71	98	79.6	22900
EW-14	10/01/86		E203	685	7.94	127	1010	90600
EW-15	10/01/86		E7.95	6.1	0.56	134	43.2	29100
NG-01	10/02/86		E2.44	4.60	0.073	107	16.9	21100
NG-02	10/02/86		E2.40	5.74	0.060	82	14.9	22300
NG-03	10/02/86		E2.18	5.55	0.040	157	11.7	21600
NG-04	10/02/86		E1.94	3.79	0.047	108	10.6	20300
NG-05	10/02/86		E1.69	2.62	0.11	65	12.4	20300
NG-06	10/08/86		E1.69	4.75	0.11	220	14.7	24900
NG-07	10/02/86		E1.21	4.87	0.054	59	14.6	27300
NG-08	10/02/86		E2.66	5.2	0.14	142	21.0	28900
NG-09	10/03/86		E6.22	9.0	0.68	170	24.9	23200
NG-10	10/03/86		E2.42	5.2	0.14	72	17.7	22100
NG-11	10/03/86	1	E4.33	3.5	0.11	94	22.1	21200
NG-11	10/03/86	2	E4.83		0.11			
NG-11	10/03/86	Mean	E4.58	3.5	0.11	94	22.1	21200
NG-12	10/15/86		E2.16	4.3	0.084	95	17.7	24600
NG-13	10/15/86		E2.18	4.63	0.068	97	20.0	23900
NG-14	10/15/86		E2.40	4.2	0.14	201	17.7	27500
NG-15	10/15/86		E2.69	5.1	0.094	271	17.2	25800
OG-01	10/09/86		E3.23	8.5	0.56	119	34.1	26600
OG-02	10/09/86		E3.27	6.6	0.64	98	30.3	24600
OG-03	10/09/86		E2.63	6.7	0.47	84	24.9	21700
OG-04	10/09/86		E3.27	8.8	0.46	94	27.8	23900
OG-05	10/09/86		E3.28	7.9	0.36	93	27.7	24000
OG-06	10/09/86		E3.51	12.7	0.57	120	37.5	29000
OG-07	10/09/86		E2.36	8.1	0.32	122	19.9	23100
PS-02	10/13/86	1	E1.31	6.7	0.070	232	15.0	29600
PS-02	10/13/86	2	E1.97		0.067			
PS-02	10/13/86	Mean	E1.64	6.7	0.068	232	15.0	29600
PS-03	10/13/86		E2.18	9.0	0.082	89	16.7	26800
PS-04	10/10/86		E1.52	10.1	0.047	145	13.6	23900
SD-01	10/09/86		E2.88	8.7	0.066	123	18.5	29800

TABLE B-1. (Continued)

Station	Sampling Date	Rep	Lead	Manganese	Nickel	Selenium	Silver	Zinc	Mercury
ES-01	10/06/86		26.6	560	29.9	U0.25	0.039	108	0.026
ES-02	10/06/86		6.2	561	34.0	U0.25	0.038	57.6	0.043
ES-03	10/06/86		8.3	527	36.3	U0.25	0.070	68.2	0.049
EW-01	10/07/86		42.3	396	50.8	0.47	0.50	256	0.205
EW-04	09/30/86		73.7	282	33.2	0.46	0.43	235	0.365
EW-07	09/30/86	1	87.9	442	47.7	U0.20	0.71	196	0.305
EW-07	09/30/86	2	90.8	513	62.7	U0.20	0.73	207	0.345
EW-07	09/30/86	3	86.3	459	54.6	U0.20	0.72	210	0.310
EW-07	09/30/86	Mean	88.3	471	55.0	U0.20	0.72	204	0.320
EW-10	10/01/86		58.6	434	52.7	0.46	0.78	198	0.466
EW-11	09/30/86		26.4	478	50.9	0.33	0.33	145	0.220
EW-12	10/01/86		10.0	380	24.1	0.33	0.030	56.2	0.062
EW-13	10/01/86		58.6	310	32.4	U0.20	0.21	272	0.273
EW-14	10/01/86		517	1050	44.0	0.47	1.03	5910	0.776
EW-15	10/01/86		38.2	495	56.2	U0.20	0.12	95.3	0.147
NG-01	10/02/86		9.5	461	33.3	0.58	0.063	49.7	0.006
NG-02	10/02/86		8.2	414	42.4	U0.25	0.029	50.7	0.014
NG-03	10/02/86		6.4	695	35.3	U0.25	0.026	41.5	0.026
NG-04	10/02/86		8.3	394	31.1	U0.25	0.033	38.0	0.016
NG-05	10/02/86		9.5	386	36.6	U0.25	0.036	44.1	0.022
NG-06	10/08/86		7.3	475	50.4	U0.25	0.041	51.5	0.018
NG-07	10/02/86		4.4	520	45.2	U0.25	0.023	47.6	0.014
NG-08	10/02/86		9.4	777	65.8	U0.25	0.079	54.8	0.027
NG-09	10/03/86		19.6	402	42.8	U0.25	0.10	76.8	0.073
NG-10	10/03/86		18.4	369	39.3	U0.25	0.039	52.1	0.024
NG-11	10/03/86	1	13.7	428	33.2	U0.25	0.051	53.4	0.022
NG-11	10/03/86	2	NR	NR	NR	U0.25	0.046	NR	0.024
NG-11	10/03/86	Mean	13.7	428	33.2	U0.25	0.048	53.4	0.023
NG-12	10/15/86		9.7	500	45.8	U0.25	0.028	55.3	0.014
NG-13	10/15/86		7.0	431	39.4	U0.25	0.034	55.2	0.018
NG-14	10/15/86		11.6	622	44.9	U0.25	0.024	95.2	0.016
NG-15	10/15/86		9.5	502	41.0	U0.25	0.028	57.9	0.012
OG-01	10/09/86		18.8	451	41.9	U0.20	0.20	83.9	0.128
OG-02	10/09/86		18.6	447	40.4	0.40	0.20	72.9	0.150
OG-03	10/09/86		17.7	416	32.2	0.41	0.17	64.7	0.119
OG-04	10/09/86		16.0	429	34.8	0.40	0.20	72.9	0.122
OG-05	10/09/86		16.5	419	30.9	0.34	0.21	64.8	0.115
OG-06	10/09/86		18.0	506	44.1	0.41	0.30	83.0	0.156
OG-07	10/09/86		12.2	464	33.7	0.40	0.086	58.2	0.078
PS-02	10/13/86	1	10.9	570	59.3	0.34	0.027	51.5	0.058
PS-02	10/13/86	2	NR	NR	NR	0.27	0.027	NR	0.054
PS-02	10/13/86	Mean	10.9	570	59.3	0.30	0.027	51.5	0.056
PS-03	10/13/86		7.9	407	65.0	0.27	0.020	50.7	0.035
PS-04	10/10/86		5.6	428	41.3	0.40	0.027	39.1	0.029
SD-01	10/09/86		8.6	631	31.5	U0.25	0.013	51.9	0.014
SD-02	10/07/86		11.3	403	28.6	U0.25	0.065	54.5	0.031

TABLE B-2. CONCENTRATIONS (UG/KG DRY WEIGHT) OF VOLATILE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: HALOGENATED ALKANES I

Station	Sampling Date	Rep	chloro-methane	bromo-methane	chloro-ethane	1,1-di-chloro-ethane	chloro-form	1,2-di-chloro-ethane
ES-02	10/06/86		U6	U6	U6	U3	U3	U3
EW-01	10/07/86	1	U27	U27	U27	U13	U13	U13
EW-01	10/07/86	2	U33	U33	U33	U16	U16	U16
EW-01	10/07/86	Mean	U27	U27	U27	U13	U13	U13
EW-02	09/30/86		U45	U45	U45	U23	U23	U23
EW-03	09/30/86		U35	U35	U35	U18	U18	U18
EW-04	09/30/86		U33	U33	U33	U16	U16	U16
EW-05	09/30/86		U41	U41	U41	U21	U21	U21
EW-06	09/30/86		U38	U38	U38	U19	U19	U19
EW-07	09/30/86	1	U27	U27	U27	U13	U13	U13
EW-07	09/30/86	2	U15	U15	U15	U8	U8	U8
EW-07	09/30/86	Mean	U15	U15	U15	U8	U8	U8
EW-08	09/30/86		U31	U31	U31	U16	U16	U16
EW-09	09/30/86		U39	U39	U39	U19	U19	U19
NG-05	10/02/86		U7	U7	U7	U3	U3	U3
NG-06	10/08/86		U7	U7	U7	U4	U4	U4
OG-03	10/09/86		U10	U10	U10	U5	U5	U5
OG-07	10/09/86		U8	U8	U8	U4	U4	U4
PS-02	10/13/86		U6	U6	U6	U3	U3	U3
PS-03	10/13/86		U6	U6	U6	U3	U3	U3
PS-04	10/10/86		U6	U6	U6	U3	U3	U3
SR-02	10/06/86		U7	U7	U7	U4	U4	U4
SS-03	10/06/86	1	U9	U9	U9	U5	U5	U5
SS-03	10/06/86	2	U9	U9	U9	U5	U5	U5
SS-03	10/06/86	Mean	U9	U9	U9	U5	U5	U5

TABLE B-3. (Continued)

Station	Sampling Date	Rep	bromo-form	1,1,2,2,-tetra-chloro-ethane
ES-02	10/06/86		U3	U3
EW-01	10/07/86	1	U13	U13
EW-01	10/07/86	2	U16	U16
EW-01	10/07/86	Mean	U13	U13
EW-02	09/30/86		U23	U23
EW-03	09/30/86		U18	U18
EW-04	09/30/86		U16	U16
EW-05	09/30/86		U21	U21
EW-06	09/30/86		U19	U19
EW-07	09/30/86	1	U13	U13
EW-07	09/30/86	2	U8	U8
EW-07	09/30/86	Mean	U8	U8
EW-08	09/30/86		U16	U16
EW-09	09/30/86		U19	U19
NG-05	10/02/86		U3	U3
NG-06	10/08/86		U4	U4
OG-03	10/09/86		U5	U5
OG-07	10/09/86		U4	U4
PS-02	10/13/86		U3	U3
PS-03	10/13/86		U3	U3
PS-04	10/10/86		U3	U3
SR-02	10/06/86		U4	U4
SS-03	10/06/86	1	U5	U5
SS-03	10/06/86	2	U5	U5
SS-03	10/06/86	Mean	U5	U5

TABLE B-4. (Continued)

Station	Sampling Date	Rep	tri-chloro-ethene	tetra-chloro-ethene
ES-02	10/06/86		U3	U3
EW-01	10/07/86	1	U13	U13
EW-01	10/07/86	2	U16	U16
EW-01	10/07/86	Mean	U13	U13
EW-02	09/30/86		U23	U23
EW-03	09/30/86		U18	U18
EW-04	09/30/86		U16	U16
EW-05	09/30/86		U21	U21
EW-06	09/30/86		U19	U19
EW-07	09/30/86	1	U13	U13
EW-07	09/30/86	2	U8	U8
EW-07	09/30/86	Mean	U8	U8
EW-08	09/30/86		U16	U16
EW-09	09/30/86		U19	U19
NG-05	10/02/86		U3	U3
NG-06	10/08/86		U4	U4
OG-03	10/09/86		U5	U5
OG-07	10/09/86		U4	U4
PS-02	10/13/86		U3	U3
PS-03	10/13/86		U3	U3
PS-04	10/10/86		U3	U3
SR-02	10/06/86		U4	U4
SS-03	10/06/86	1	U5	U5
SS-03	10/06/86	2	U5	U5
SS-03	10/06/86	Mean	U5	U5

TABLE B-6. CONCENTRATIONS (UG/KG DRY WEIGHT) OF VOLATILE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: CHLORINATED AROMATIC HYDROCARBONS

Station	Date	Rep	chlorobenzene
ES-02	10/06/86		U3
EW-01	10/07/86	1	U13
EW-01	10/07/86	2	U16
EW-01	10/07/86	Mean	U13
EW-02	09/30/86		U23
EW-03	09/30/86		U18
EW-04	09/30/86		U16
EW-05	09/30/86		U21
EW-06	09/30/86		U19
EW-07	09/30/86	1	U13
EW-07	09/30/86	2	U8
EW-07	09/30/86	Mean	U8
EW-08	09/30/86		U16
EW-09	09/30/86		U19
NG-05	10/02/86		U3
NG-06	10/08/86		U4
OG-03	10/09/86		U5
OG-07	10/09/86		U4
PS-02	10/13/86		U3
PS-03	10/13/86		U3
PS-04	10/10/86		U3
SR-02	10/06/86		U4
SS-03	10/06/86	1	U5
SS-03	10/06/86	2	U5
SS-03	10/06/86	Mean	U5

TABLE B-8. CONCENTRATIONS (UG/KG DRY WEIGHT) OF VOLATILE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: KETONES

Station	Sampling Date	Rep	acetone	2-butanone	2-hexanone	4-methyl-2-pentanone
ES-02	10/06/86		U6	U6	U6	U6
EW-01	10/07/86	1	U27	U27	U27	U27
EW-01	10/07/86	2	U33	U33	U33	U33
EW-01	10/07/86	Mean	U27	U27	U27	U27
EW-02	09/30/86		U45	U45	U45	U45
EW-03	09/30/86		U35	U35	U35	U35
EW-04	09/30/86		U33	U33	U33	U33
EW-05	09/30/86		230	U41	U41	U41
EW-06	09/30/86		140	U38	U38	U38
EW-07	09/30/86	1	150	U27	U27	U27
EW-07	09/30/86	2	U15	U15	U15	U15
EW-07	09/30/86	Mean	L82	U15	U15	U15
EW-08	09/30/86		U31	U31	U31	U31
EW-09	09/30/86		120	U39	U39	U39
NG-05	10/02/86		U7	U7	U7	U7
NG-06	10/08/86		U7	U7	U7	U7
OG-03	10/09/86		U10	U10	U10	U10
OG-07	10/09/86		U8	U8	U8	U8
PS-02	10/13/86		U6	U6	U6	U6
PS-03	10/13/86		U6	U6	U6	U6
PS-04	10/10/86		U6	U6	U6	U6
SR-02	10/06/86		U7	U7	U7	U7
SS-03	10/06/86	1	U9	U9	U9	U9
SS-03	10/06/86	2	U9	U9	U9	U9
SS-03	10/06/86	Mean	U9	U9	U9	U9

TABLE B-10. CONCENTRATIONS (UG/KG DRY WEIGHT) OF EXTRACTABLE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: PHENOL AND ALKYL-SUBSTITUTED PHENOLS

Station	Date	Rep	phenol	2-methyl-phenol	4-methyl-phenol	2,4-dimethyl-phenol
ES-01	10/06/86		B25	U10	140	U10
ES-02	10/06/86		B25	U10	47	U10
ES-03	10/06/86		Z1200	U20	1400	U10
EW-01	10/07/86		Z1600	U50	6000	U20
EW-04	09/30/86		2100	1200	35000	520
EW-07	09/30/86	1	1100	X580	X130000	140
EW-07	09/30/86	2	730	U200	24000	U50
EW-07	09/30/86	3	1300	U200	X140000	120
EW-07	09/30/86	Mean	1000	LX330	X98000	L100
EW-10	10/01/86		2900	U200	X26000	U50
EW-11	09/30/86		1200	U50	7300	U50
EW-12	10/01/86		200	U200	X3600	U50
EW-13	10/01/86		1200	U50	25000	U20
EW-14	10/01/86		1300	U50	15000	U20
EW-15	10/01/86		470	U200	7200	U50
NG-01	10/02/86		150	U50	X500	U20
NG-02	10/02/86		88	U100	X550	U50
NG-03	10/02/86		94	U200	X970	U50
NG-04	10/02/86		X290	U200	X2400	U50
NG-05	10/02/86		310	U50	X9700	U20
NG-06	10/08/86		Z250	U50	320	U50
NG-07	10/02/86		110	U100	X440	U50
NG-08	10/02/86		240	U100	X930	U50
NG-09	10/03/86		2100	U100	2400	U50
NG-10	10/03/86		1000	U10	1800	U20
NG-11	10/03/86		1100	U100	1600	U50
NG-12	10/15/86		B17	U20	U20	U10
NG-13	10/15/86		Z800	U20	320	U10
NG-14	10/15/86		Z1200	U20	2100	U10
NG-15	10/15/86		Z710	U20	760	U10
OG-01	10/09/86		Z450	U50	1300	U50
OG-02	10/09/86		Z410	6	1000	U50
OG-03	10/09/86		Z410	U10	1100	U20
OG-04	10/09/86		Z430	U50	1200	U50
OG-05	10/09/86		Z310	U10	910	U10
OG-06	10/09/86		Z410	U10	720	U50
OG-07	10/09/86		Z250	U10	350	U10
PS-02	10/13/86		Z200	U50	290	U10
PS-03	10/13/86		Z110	U50	84	U10
PS-04	10/10/86		Z140	U20	140	U10
SD-01	10/09/86		B22	U10	X3	U10
SD-02	10/07/86		Z99	U20	27	U10
SD-03	10/02/86		130	U100	X760	U50
SR-01	10/06/86		67	U50	360	U50
SR-02	10/06/86		18	U50	U50	U50

TABLE B-11. CONCENTRATIONS (UG/KG DRY WEIGHT) OF EXTRACTABLE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: SUBSTITUTED PHENOLS

Station	Sampling Date	Rep	2-chlorophenol	2,4-dichlorophenol	4-chloro-3-methylphenol	2,4,6-trichlorophenol	2,4,5-trichlorophenol	pentachlorophenol
ES-01	10/06/86		U200	U10	U10	U20	U20	U500
ES-02	10/06/86		U20	U50	U50	U50	U50	U1000
ES-03	10/06/86		U100	U20	U10	U500	U500	U1000
EW-01	10/07/86		U20	U20	U20	U100	U100	U200
EW-04	09/30/86		U100	U100	U50	U200	U200	U200
EW-07	09/30/86	1	U20	U20	U50	U50	U50	U20
EW-07	09/30/86	2	U20	U20	U50	U50	U50	U20
EW-07	09/30/86	3	U100	U100	U50	U200	U200	U200
EW-07	09/30/86	Mean	U20	U20	U50	U50	U50	U20
EW-10	10/01/86		U20	U20	U50	U20	U20	U20
EW-11	09/30/86		U20	U20	U50	U50	U50	U50
EW-12	10/01/86		U300	U500	U50	U200	U200	U200
EW-13	10/01/86		U100	U250	U20	U50	U50	U500
EW-14	10/01/86		U20	U20	U20	U50	U50	U50
EW-15	10/01/86		U50	U20	U50	U50	U50	U50
NG-01	10/02/86		U100	U250	U20	U50	U200	U500
NG-02	10/02/86		U100	U500	U50	U200	U200	U200
NG-03	10/02/86		U150	U100	U50	U200	U200	U200
NG-04	10/02/86		U200	U200	U50	U200	U200	U200
NG-05	10/02/86		U100	U250	U20	U50	U50	U100
NG-06	10/08/86		U20	U50	U50	U100	U100	U50
NG-07	10/02/86		U50	U20	U50	U50	U50	U50
NG-08	10/02/86		U50	U20	U50	U50	U50	U50
NG-09	10/03/86		U20	U50	U50	U50	U50	U50
NG-10	10/03/86		U20	U10	U20	U50	U50	U50
NG-11	10/03/86		U20	U20	U50	U20	U20	U50
NG-12	10/15/86		U10	U20	U50	U50	U50	U1000
NG-13	10/15/86		U10	U10	U10	U50	U50	U1000
NG-14	10/15/86		U10	U10	U50	U50	U50	U1000
NG-15	10/15/86		U10	U20	U50	U100	U100	U1000
OG-01	10/09/86		U20	U20	U50	U20	U20	U50
OG-02	10/09/86		U10	U10	U50	U10	U10	U20
OG-03	10/09/86		U20	U20	U20	U50	U50	U50
OG-04	10/09/86		U20	U20	U50	U50	U50	U200
OG-05	10/09/86		U10	U10	U10	U10	U10	U50
OG-06	10/09/86		U20	U50	U10	U100	U100	U1000
OG-07	10/09/86		U10	U10	U50	U20	U20	U100
PS-02	10/13/86		U500	U50	U50	U100	U100	U1000
PS-03	10/13/86		U10	U10	U50	U50	U50	U500
PS-04	10/10/86		U10	U10	U10	U50	U50	U100
SD-01	10/09/86		U1000	U10	U50	U20	U20	U20
SD-02	10/07/86		U100	U100	U10	U200	U200	U500
SD-03	10/02/86		U20	U50	U50	U50	U50	U50
SR-01	10/06/86		U20	U20	U50	U20	U20	U100

TABLE B-11. (Continued)

Station	Sampling Date	Rep	2-nitro-phenol	2,4-dinitro-phenol	4,6-dinitro-2-methyl-phenol	4-nitro-phenol
ES-01	10/06/86		U50	U50	U100	U50
ES-02	10/06/86		U50	U50	U100	U50
ES-03	10/06/86		U50	U50	U100	U50
EW-01	10/07/86		U50	U50	U100	U50
EW-04	09/30/86		U50	U50	U100	U50
EW-07	09/30/86	1	U50	U50	U100	U50
EW-07	09/30/86	2	U50	U50	U100	U50
EW-07	09/30/86	3	U50	U50	U100	U50
EW-07	09/30/86	Mean	U50	U50	U100	U50
EW-10	10/01/86		U50	U50	U100	U50
EW-11	09/30/86		U50	U50	U100	U50
EW-12	10/01/86		U50	U50	U100	U50
EW-13	10/01/86		U50	U50	U100	U50
EW-14	10/01/86		U50	U50	U100	U50
EW-15	10/01/86		U50	U50	U100	U50
NG-01	10/02/86		U50	U50	U100	U50
NG-02	10/02/86		U50	U50	U100	U50
NG-03	10/02/86		U50	U50	U100	U50
NG-04	10/02/86		U50	U50	U100	U50
NG-05	10/02/86		U50	U50	U100	U50
NG-06	10/08/86		U50	U50	U100	U50
NG-07	10/02/86		U50	U50	U100	U50
NG-08	10/02/86		U50	U50	U100	U50
NG-09	10/03/86		U50	U50	U100	U50
NG-10	10/03/86		U50	U50	U100	U50
NG-11	10/03/86		U50	U50	U100	U50
NG-12	10/15/86		U50	U50	U100	U50
NG-13	10/15/86		U50	U50	U100	U50
NG-14	10/15/86		U50	U50	U100	U50
NG-15	10/15/86		U50	U50	U100	U50
OG-01	10/09/86		U50	U50	U100	U50
OG-02	10/09/86		U50	U50	U100	U50
OG-03	10/09/86		U50	U50	U100	U50
OG-04	10/09/86		U50	U50	U100	U50
OG-05	10/09/86		U50	U50	U100	U50
OG-06	10/09/86		U50	U50	U100	U50
OG-07	10/09/86		U50	U50	U100	U50
PS-02	10/13/86		U50	U50	U100	U50
PS-03	10/13/86		U50	U50	U100	U50
PS-04	10/10/86		U50	U50	U100	U50
SD-01	10/09/86		U50	U50	U100	U50
SD-02	10/07/86		U50	U50	U100	U50
SD-03	10/02/86		U50	U50	U100	U50
SR-01	10/06/86		U50	U50	U100	U50
SR-02	10/06/86		U50	U50	U100	U50

TABLE B-12. CONCENTRATIONS (UG/KG DRY WEIGHT) OF EXTRACTABLE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: LOW MOLECULAR WEIGHT AROMATIC HYDROCARBONS

Station	Sampling Date	Rep	naphthalene	acenaphthalene	acenaphthene	fluorene	phenanthrene	anthracene
ES-01	10/06/86		13	3	6	U10	16	9
ES-02	10/06/86		B10	6	3	U10	14	6
ES-03	10/06/86		Z64	15	9	15	58	15
EW-01	10/07/86		Z560	100	190	280	440	210
EW-04	09/30/86		10000	620	3300	2300	8100	690
EW-07	09/30/86	1	X19000	290	1600	1200	1600	840
EW-07	09/30/86	2	7900	220	1700	1400	1300	1500
EW-07	09/30/86	3	X23000	420	2100	1600	2100	1300
EW-07	09/30/86	Mean	X17000	310	1800	1400	1700	1200
EW-10	10/01/86		X2200	320	320	440	1100	820
EW-11	09/30/86		1000	480	150	150	360	210
EW-12	10/01/86		X970	30	100	73	170	91
EW-13	10/01/86		12000	370	3400	2300	2700	3400
EW-14	10/01/86		7000	800	5200	4300	4800	6100
EW-15	10/01/86		2500	160	740	420	830	280
NG-01	10/02/86		X140	4	8	U10	27	11
NG-02	10/02/86		X67	U10	7	U10	13	4
NG-03	10/02/86		X93	U10	U10	U10	11	3
NG-04	10/02/86		X160	6	U10	U10	23	8
NG-05	10/02/86		X240	6	9	U10	25	9
NG-06	10/08/86		Z23	8	8	U10	53	26
NG-07	10/02/86		X52	8	9	6	23	16
NG-08	10/02/86		X190	15	11	U10	52	32
NG-09	10/03/86		1000	310	510	510	Z890	910
NG-10	10/03/86		93	31	110	140	Z440	340
NG-11	10/03/86		190	96	560	610	Z1200	870
NG-12	10/15/86		B3	U10	U10	U10	11	3
NG-13	10/15/86		B6	U10	U10	U10	10	4
NG-14	10/15/86		U10	U10	16	37	360	29
NG-15	10/15/86		4	U10	U10	U10	11	U10
OG-01	10/09/86		Z360	91	59	67	200	61
OG-02	10/09/86		Z380	85	62	62	200	100
OG-03	10/09/86		Z410	95	45	45	170	55
OG-04	10/09/86		Z350	81	41	59	170	97
OG-05	10/09/86		Z250	56	23	39	91	35
OG-06	10/09/86		Z290	36	34	45	150	45
OG-07	10/09/86		Z340	83	49	49	200	78
PS-02	10/13/86		B3	U10	U10	U10	5	1
PS-03	10/13/86		B3	U10	U10	U10	7	2
PS-04	10/10/86		U10	1	U10	U10	4	1
SD-01	10/09/86		XB3	U10	U10	U10	3	U10
SD-02	10/07/86		Z92	17	7	U10	40	19
SD-03	10/02/86		X250	33	19	U10	56	30
SR-01	10/06/86		11	U10	2	U10	B10	5

TABLE B-13. CONCENTRATIONS (UG/KG DRY WEIGHT) OF EXTRACTABLE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: HIGH MOLECULAR WEIGHT AROMATIC HYDROCARBONS

Station	Sampling Date	Rep	fluor-anthene	pyrene	benzo-(a)-anthra-cene	chrysene	benzo-(a)-pyrene	indeno-(1,2,3-cd)-pyrene
ES-01	10/06/86		37	32	16	21	14	10
ES-02	10/06/86		35	29	13	19	13	11
ES-03	10/06/86		75	62	23	32	17	8
EW-01	10/07/86		770	610	160	280	140	70
EW-04	09/30/86		2300	2300	810	1200	420	300
EW-07	09/30/86	1	1600	1300	450	740	180	89
EW-07	09/30/86	2	1600	1500	410	400	190	98
EW-07	09/30/86	3	1900	1800	470	1100	320	150
EW-07	09/30/86	Mean	1700	1500	440	750	230	110
EW-10	10/01/86		1500	1300	620	1700	290	140
EW-11	09/30/86		700	450	18	210	82	67
EW-12	10/01/86		260	220	89	130	75	41
EW-13	10/01/86		3700	3000	960	940	480	300
EW-14	10/01/86		3400	5500	3200	3200	1700	730
EW-15	10/01/86		910	810	210	300	190	120
NG-01	10/02/86		36	34	11	15	9	5
NG-02	10/02/86		14	16	5	7	4	3
NG-03	10/02/86		11	13	4	6	4	U10
NG-04	10/02/86		40	45	11	13	7	4
NG-05	10/02/86		40	40	11	16	12	8
NG-06	10/08/86		76	89	35	53	36	19
NG-07	10/02/86		83	80	42	59	42	25
NG-08	10/02/86		87	82	34	63	40	25
NG-09	10/03/86		1200	Z1300	980	1300	1000	580
NG-10	10/03/86		610	Z500	310	490	200	98
NG-11	10/03/86		1600	Z1400	1100	1100	820	500
NG-12	10/15/86		16	16	7	8	6	4
NG-13	10/15/86		U10	14	7	18	5	U10
NG-14	10/15/86		340	Z230	42	81	26	18
NG-15	10/15/86		16	B10	4	7	4	U10
OG-01	10/09/86		200	200	37	61	35	20
OG-02	10/09/86		200	Z170	100	130	85	38
OG-03	10/09/86		170	170	42	56	40	24
OG-04	10/09/86		190	190	47	71	45	28
OG-05	10/09/86		110	100	25	39	23	12
OG-06	10/09/86		130	120	30	49	28	21
OG-07	10/09/86		180	230	45	71	45	29
PS-02	10/13/86		5	7	3	4	1	U10
PS-03	10/13/86		7	6	3	5	3	3
PS-04	10/10/86		5	5	2	4	1	1
SD-01	10/09/86		3	3	1	1	U10	U10
SD-02	10/07/86		54	56	14	19	13	9
SD-03	10/02/86		67	63	21	31	22	11
SR-01	10/06/86		10	B10	4	6	4	U10

TABLE B-13. (Continued)

Station	Sampling Date	Rep	di-benzo-(a,h)-anthracene	benzo-(g,h,i) perylene	benzo-(b+k)-fluoranthenes
ES-01	10/06/86		7	11	32
ES-02	10/06/86		7	14	24
ES-03	10/06/86		U10	15	40
EW-01	10/07/86		30	87	320
EW-04	09/30/86		160	210	1100
EW-07	09/30/86	1	34	84	530
EW-07	09/30/86	2	37	84	390
EW-07	09/30/86	3	92	140	760
EW-07	09/30/86	Mean	54	100	560
EW-10	10/01/86		44	120	820
EW-11	09/30/86		39	82	250
EW-12	10/01/86		22	36	170
EW-13	10/01/86		74	270	1100
EW-14	10/01/86		270	550	4100
EW-15	10/01/86		57	96	340
NG-01	10/02/86		U10	5	19
NG-02	10/02/86		U10	3	10
NG-03	10/02/86		U10	U10	8
NG-04	10/02/86		U10	3	19
NG-05	10/02/86		U10	7	21
NG-06	10/08/86		6	19	72
NG-07	10/02/86		6	21	110
NG-08	10/02/86		7	23	82
NG-09	10/03/86		180	440	2000
NG-10	10/03/86		36	63	460
NG-11	10/03/86		140	400	1600
NG-12	10/15/86		U10	5	11
NG-13	10/15/86		U10	3	11
NG-14	10/15/86		10	19	70
NG-15	10/15/86		U10	4	10
OG-01	10/09/86		7	28	74
OG-02	10/09/86		14	38	140
OG-03	10/09/86		U10	29	65
OG-04	10/09/86		8	33	79
OG-05	10/09/86		4	14	40
OG-06	10/09/86		U10	23	55
OG-07	10/09/86		11	37	78
PS-02	10/13/86		U10	3	5
PS-03	10/13/86		2	4	U10
PS-04	10/10/86		U10	3	5
SD-01	10/09/86		U10	U10	U10
SD-02	10/07/86		U10	12	26
SD-03	10/02/86		U10	13	38
SR-01	10/06/86		U10	3	U10

TABLE B-14. CONCENTRATIONS (UG/KG DRY WEIGHT) OF EXTRACTABLE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: CHLORINATED AROMATIC HYDROCARBONS

Station	Sampling Date	Rep	1,3-dichloro-benzene	1,4-dichloro-benzene	1,2-dichloro-benzene	1,2,4-tri-chloro-benzene	2-chloro-naphtha-lene	hexa-chloro-benzene
ES-01	10/06/86		U10	3	U10	U10	U10	U10
ES-02	10/06/86		U10	U10	U10	U10	U10	U10
ES-03	10/06/86		U10	U10	U10	U10	U10	U10
EW-01	10/07/86		U10	12	U10	U10	U10	U20
EW-04	09/30/86		U50	U50	96	U20	U50	U50
EW-07	09/30/86	1	U200	U100	U200	U200	U50	U50
EW-07	09/30/86	2	U100	U100	U100	U50	U50	U50
EW-07	09/30/86	3	U200	U200	U200	U200	U50	U20
EW-07	09/30/86	Mean	U100	U100	U100	U50	U50	U20
EW-10	10/01/86		U100	U100	U100	U50	U50	U50
EW-11	09/30/86		U50	U50	U50	U20	U50	U50
EW-12	10/01/86		U500	U500	U500	U200	U50	U50
EW-13	10/01/86		U150	U150	U150	U50	U10	U20
EW-14	10/01/86		U150	U150	U150	U50	U10	U20
EW-15	10/01/86		U100	U100	U100	U200	U50	U50
NG-01	10/02/86		U150	U150	U150	U50	U10	U50
NG-02	10/02/86		U200	U200	U200	U200	U50	U50
NG-03	10/02/86		U200	U200	U200	U200	U50	U50
NG-04	10/02/86		U200	U200	U200	U200	U50	U50
NG-05	10/02/86		U150	U150	U150	U50	U10	U20
NG-06	10/08/86		U10	U10	U10	U10	U50	U50
NG-07	10/02/86		U100	U100	U100	U50	U50	U50
NG-08	10/02/86		U100	U100	U100	U20	U50	U50
NG-09	10/03/86		U10	20	9	U10	U50	U50
NG-10	10/03/86		U10	11	13	U10	U10	U10
NG-11	10/03/86		U10	U10	U10	U10	U50	U50
NG-12	10/15/86		U10	U10	U10	U10	U50	U10
NG-13	10/15/86		U10	U10	U10	U10	U50	U10
NG-14	10/15/86		U10	U10	U10	U10	U50	U20
NG-15	10/15/86		U10	U10	U10	U10	U50	U10
OG-01	10/09/86		U10	5	U10	U10	U50	U50
OG-02	10/09/86		U10	25	7	U10	U50	U10
OG-03	10/09/86		U10	5	U10	U10	U10	U10
OG-04	10/09/86		U10	6	U10	U10	U50	U50
OG-05	10/09/86		U10	3	U10	U10	U50	U10
OG-06	10/09/86		U10	12	U10	U10	U50	U10
OG-07	10/09/86		U10	6	U10	U10	U10	U10
PS-02	10/13/86		U10	U10	U10	U10	U50	U10
PS-03	10/13/86		U10	U10	U10	U10	U50	U10
PS-04	10/10/86		U10	U10	U10	U10	U50	U10
SD-01	10/09/86		U10	U10	U10	U10	U50	U10
SD-02	10/07/86		U10	U10	U10	U10	U10	U10
SD-03	10/02/86		U50	U50	U50	U20	U50	U50
SR-01	10/06/86		U10	2	U10	U10	U50	U50

TABLE B-15. CONCENTRATIONS (UG/KG DRY WEIGHT) OF EXTRACTABLE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: CHLORINATED ALIPHATIC HYDROCARBONS

Station	Sampling Date	Rep	hexa-chloro-ethane	hexa-chloro-butadiene	hexa-chloro-cyclo-penta-diene
ES-01	10/06/86		U20	U20	U200
ES-02	10/06/86		U20	U20	U200
ES-03	10/06/86		U20	U10	U200
EW-01	10/07/86		U20	U10	U200
EW-04	09/30/86		U20	U50	U200
EW-07	09/30/86	1	U20	U200	U200
EW-07	09/30/86	2	U20	U100	U200
EW-07	09/30/86	3	U20	U200	U200
EW-07	09/30/86	Mean	U20	U100	U200
EW-10	10/01/86		U20	U100	U200
EW-11	09/30/86		U20	U50	U200
EW-12	10/01/86		U20	U200	U200
EW-13	10/01/86		U20	U300	U200
EW-14	10/01/86		U20	U200	U200
EW-15	10/01/86		U20	U200	U200
NG-01	10/02/86		U20	U300	U200
NG-02	10/02/86		U20	U200	U200
NG-03	10/02/86		U20	U200	U200
NG-04	10/02/86		U20	U200	U200
NG-05	10/02/86		U20	U200	U200
NG-06	10/08/86		U20	U10	U200
NG-07	10/02/86		U20	U100	U200
NG-08	10/02/86		U20	U100	U200
NG-09	10/03/86		U20	U10	U200
NG-10	10/03/86		U20	U10	U200
NG-11	10/03/86		U20	U10	U200
NG-12	10/15/86		U20	U10	U200
NG-13	10/15/86		U20	U10	U200
NG-14	10/15/86		U20	U20	U200
NG-15	10/15/86		U20	U20	U200
OG-01	10/09/86		U20	U10	U200
OG-02	10/09/86		U20	U10	U200
OG-03	10/09/86		U20	U10	U200
OG-04	10/09/86		U20	U10	U200
OG-05	10/09/86		U20	U10	U200
OG-06	10/09/86		U20	U10	U200
OG-07	10/09/86		U20	U10	U200
PS-02	10/13/86		U20	U10	U200
PS-03	10/13/86		U20	U10	U200
PS-04	10/10/86		U20	U10	U200
SD-01	10/09/86		U20	U10	U200
SD-02	10/07/86		U20	U10	U200
SD-03	10/02/86		U20	U50	U200

TABLE B-16. CONCENTRATIONS (UG/KG DRY WEIGHT) OF EXTRACTABLE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: HALOGENATED ETHERS

Station	Sampling Date	Rep	bis(2-chloro-ethyl) ether	bis(2-chloro-isopropyl ether	bis(2-chloro-ethoxy) methane	4-chloro-phenyl-phenyl-ether	4-bromo-phenyl-phenyl-ether
ES-01	10/06/86		U20	U10	U10	U10	U10
ES-02	10/06/86		U20	U10	U10	U10	U10
ES-03	10/06/86		U20	U10	U10	U10	U10
EW-01	10/07/86		U20	U10	U10	U10	U10
EW-04	09/30/86		U20	U10	U10	U10	U10
EW-07	09/30/86	1	U20	U10	U10	U10	U10
EW-07	09/30/86	2	U20	U10	U10	U10	U10
EW-07	09/30/86	3	U20	U10	U10	U10	U10
EW-07	09/30/86	Mean	U20	U10	U10	U10	U10
EW-10	10/01/86		U20	U10	U10	U10	U10
EW-11	09/30/86		U20	U10	U10	U10	U10
EW-12	10/01/86		U20	U10	U10	U10	U10
EW-13	10/01/86		U20	U10	U10	U10	U10
EW-14	10/01/86		U20	U10	U10	U10	U10
EW-15	10/01/86		U20	U10	U10	U10	U10
NG-01	10/02/86		U20	U10	U10	U10	U10
NG-02	10/02/86		U20	U10	U10	U10	U10
NG-03	10/02/86		U20	U10	U10	U10	U10
NG-04	10/02/86		U20	U10	U10	U10	U10
NG-05	10/02/86		U20	U10	U10	U10	U10
NG-06	10/08/86		U20	U10	U10	U10	U10
NG-07	10/02/86		U20	U10	U10	U10	U10
NG-08	10/02/86		U20	U10	U10	U10	U10
NG-09	10/03/86		U20	U10	U10	U10	U10
NG-10	10/03/86		U20	U10	U10	U10	U10
NG-11	10/03/86		U20	U10	U10	U10	U10
NG-12	10/15/86		U20	U10	U10	U10	U10
NG-13	10/15/86		U20	U10	U10	U10	U10
NG-14	10/15/86		U20	U10	U10	U10	U10
NG-15	10/15/86		U20	U10	U10	U10	U10
OG-01	10/09/86		U20	U10	U10	U10	U10
OG-02	10/09/86		U20	U10	U10	U10	U10
OG-03	10/09/86		U20	U10	U10	U10	U10
OG-04	10/09/86		U20	U10	U10	U10	U10
OG-05	10/09/86		U20	U10	U10	U10	U10
OG-06	10/09/86		U20	U10	U10	U10	U10
OG-07	10/09/86		U20	U10	U10	U10	U10
PS-02	10/13/86		U20	U10	U10	U10	U10
PS-03	10/13/86		U20	U10	U10	U10	U10
PS-04	10/10/86		U20	U10	U10	U10	U10
SD-01	10/09/86		U20	U10	U10	U10	U10
SD-02	10/07/86		U20	U10	U10	U10	U10
SD-03	10/02/86		U20	U10	U10	U10	U10
SR-01	10/06/86		U20	U10	U10	U10	U10

TABLE B-17. CONCENTRATIONS (UG/KG DRY WEIGHT) OF EXTRACTABLE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: PHTHALATES

Station	Sampling Date	Rep	di-methyl-phthalate	di-ethyl-phthalate	di-n-butyl-phthalate	butyl-benzyl-phthalate	bis-(2-ethyl-hexyl)-phthalate	di-n-octyl-phthalate
ES-01	10/06/86		U10	U10	B10	10	U10	U10
ES-02	10/06/86		U10	U10	B10	U10	Z17	U10
ES-03	10/06/86		U10	U10	Z54	U10	Z49	U10
EW-01	10/07/86		U20	U10	Z180	70	Z190	U10
EW-04	09/30/86		U10	U10	U10	U10	650	U10
EW-07	09/30/86	1	U10	U10	290	U10	160	U10
EW-07	09/30/86	2	U10	U10	97	U10	220	U10
EW-07	09/30/86	3	U10	U10	140	U10	230	U10
EW-07	09/30/86	Mean	U10	U10	180	U10	200	U10
EW-10	10/01/86		U10	U10	71	U10	410	U10
EW-11	09/30/86		U10	U10	170	U10	94	U10
EW-12	10/01/86		U10	U10	31	U10	110	U10
EW-13	10/01/86		U20	U10	260	U20	440	U10
EW-14	10/01/86		U20	U10	U10	U20	930	U10
EW-15	10/01/86		U10	U10	51	U10	170	U10
NG-01	10/02/86		U20	8	U10	U20	42	U10
NG-02	10/02/86		26	11	41	U10	36	U10
NG-03	10/02/86		U10	U10	45	U10	40	U10
NG-04	10/02/86		U10	U10	25	U10	39	U10
NG-05	10/02/86		8	U10	16	U20	33	U10
NG-06	10/08/86		U10	U10	B10	U10	B10	U10
NG-07	10/02/86		U10	5	30	U10	41	U10
NG-08	10/02/86		U10	U10	16	U10	29	U10
NG-09	10/03/86		U10	U10	B10	U10	Z38	U10
NG-10	10/03/86		U10	U10	B10	U10	Z41	U10
NG-11	10/03/86		U10	U10	B10	U10	Z50	U10
NG-12	10/15/86		U10	U10	B10	U10	Z14	U10
NG-13	10/15/86		U10	U10	B10	U10	B10	U10
NG-14	10/15/86		U10	U10	B10	36	Z17	U10
NG-15	10/15/86		U10	U10	B10	11	Z41	U10
OG-01	10/09/86		U10	U10	Z150	U10	Z30	U10
OG-02	10/09/86		U10	U10	Z32	U10	Z37	U10
OG-03	10/09/86		U10	U10	Z16	U10	U10	U10
OG-04	10/09/86		U10	U10	B10	U10	Z33	U10
OG-05	10/09/86		U10	U10	B10	U10	Z28	U10
OG-06	10/09/86		U10	U10	B10	U10	Z220	U10
OG-07	10/09/86		U10	U10	B10	U10	Z12	U10
PS-02	10/13/86		U10	U10	B10	U10	B10	U10
PS-03	10/13/86		U10	U10	B10	U10	Z58	B3
PS-04	10/10/86		U10	U10	B10	U10	B10	U10
SD-01	10/09/86		U10	U10	B10	U10	B10	B4
SD-02	10/07/86		U10	U10	Z40	20	B10	U10
SD-03	10/02/86		U10	11	53	U10	53	U10
SR-01	10/06/86		U10	U10	U10	U10	B10	U10

TABLE B-18. CONCENTRATIONS (UG/KG DRY WEIGHT) OF EXTRACTABLE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: MISCELLANEOUS OXYGENATED COMPOUNDS

Station	Sampling Date	Rep	iso-phorone	benzyl alcohol	benzoic acid	dibenzo-furan
ES-01	10/06/86		U50	U200	E10	7
ES-02	10/06/86		U50	U20	E10	6
ES-03	10/06/86		U50	U20	E760	15
EW-01	10/07/86		U10	U20	U100	230
EW-04	09/30/86		U50	810	U800	2200
EW-07	09/30/86	1	U50	U200	U200	1400
EW-07	09/30/86	2	U50	U100	U200	1500
EW-07	09/30/86	3	U50	U100	U200	1800
EW-07	09/30/86	Mean	U50	U100	U200	1600
EW-10	10/01/86		U50	U100	U800	470
EW-11	09/30/86		U50	58	U800	180
EW-12	10/01/86		U50	U200	U800	110
EW-13	10/01/86		U10	U100	U200	3100
EW-14	10/01/86		U10	U100	5900	5000
EW-15	10/01/86		U50	U100	U50	470
NG-01	10/02/86		U10	U100	U200	19
NG-02	10/02/86		U50	U100	U200	U10
NG-03	10/02/86		U50	U100	U200	U10
NG-04	10/02/86		U50	U200	U800	16
NG-05	10/02/86		U10	U100	X2100	16
NG-06	10/08/86		U50	U20	E10	13
NG-07	10/02/86		U50	U100	X1700	11
NG-08	10/02/86		U50	U100	X1300	20
NG-09	10/03/86		U50	U20	U100	U10
NG-10	10/03/86		U10	U10	U10	130
NG-11	10/03/86		U50	U20	240	470
NG-12	10/15/86		U50	U20	U100	U10
NG-13	10/15/86		U50	U20	U100	52
NG-14	10/15/86		U50	U20	U100	21
NG-15	10/15/86		U50	U20	80	U10
OG-01	10/09/86		U50	U20	U100	76
OG-02	10/09/86		U50	11	U800	58
OG-03	10/09/86		U10	U10	U10	64
OG-04	10/09/86		U50	U20	U100	62
OG-05	10/09/86		U50	U20	U100	39
OG-06	10/09/86		U50	U10	E150	49
OG-07	10/09/86		U50	U20	U100	U10
PS-02	10/13/86		U50	U200	U100	U10
PS-03	10/13/86		U50	U20	E10	11
PS-04	10/10/86		U50	U20	U100	U10
SD-01	10/09/86		U50	U20	U100	U10
SD-02	10/07/86		U50	U20	E36	12
SD-03	10/02/86		U50	X99	X770	28
SR-01	10/06/86		U50	U20	160	U10
SR-02	10/06/86		U50	U20	70	3
SR-03	10/06/86		U50	U20	78	10

TABLE B-19. CONCENTRATIONS (UG/KG DRY WEIGHT) OF EXTRACTABLE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: ORGANONITROGEN COMPOUNDS

Station	Sampling Date	Rep	nitro-benzene	nitroso-di-n-propyl-amine	4-chloro-aniline	2-nitro-aniline	3-nitro-aniline	4-nitro-aniline
ES-01	10/06/86		U10	U10	U10	U10	U50	U100
ES-02	10/06/86		U10	U10	U10	U10	U50	U100
ES-03	10/06/86		U10	U10	U10	U10	U50	U100
EW-01	10/07/86		U10	U10	U10	U50	U50	U100
EW-04	09/30/86		U10	U10	U10	U10	U50	U100
EW-07	09/30/86	1	U10	U10	U10	U10	U50	U100
EW-07	09/30/86	2	U10	U10	U10	U10	U50	U100
EW-07	09/30/86	3	U10	U10	U10	U10	U50	U100
EW-07	09/30/86	Mean	U10	U10	U10	U10	U50	U100
EW-10	10/01/86		U10	U10	U10	U10	U50	U100
EW-11	09/30/86		U10	U10	U10	U10	U50	U100
EW-12	10/01/86		U10	U10	U10	U10	U50	U100
EW-13	10/01/86		U10	U10	U10	U50	U50	U100
EW-14	10/01/86		U10	U10	U10	U50	U50	U100
EW-15	10/01/86		U10	U10	U10	U10	U50	U100
NG-01	10/02/86		U10	U10	U10	U50	U50	U100
NG-02	10/02/86		U10	U10	U10	U10	U50	U100
NG-03	10/02/86		U10	U10	U10	U10	U50	U100
NG-04	10/02/86		U10	U10	U10	U10	U50	U100
NG-05	10/02/86		U10	U10	U10	U50	U50	U100
NG-06	10/08/86		U10	U10	U10	U10	U50	U100
NG-07	10/02/86		U10	U10	U10	U10	U50	U100
NG-08	10/02/86		U10	U10	U10	U10	U50	U100
NG-09	10/03/86		U10	U10	U10	U10	U50	U100
NG-10	10/03/86		U10	U10	U10	U10	U50	U100
NG-11	10/03/86		U10	U10	U10	U10	U50	U100
NG-12	10/15/86		U10	U10	U10	U10	U50	U100
NG-13	10/15/86		U10	U10	U10	U10	U50	U100
NG-14	10/15/86		U10	U10	U10	U10	U50	U100
NG-15	10/15/86		U10	U10	U10	U10	U50	U100
OG-01	10/09/86		U10	U10	U10	U10	U50	U100
OG-02	10/09/86		U10	U10	U10	U10	U50	U100
OG-03	10/09/86		U10	U10	U10	U10	U50	U100
OG-04	10/09/86		U10	U10	U10	U10	U50	U100
OG-05	10/09/86		U10	U10	U10	U10	U50	U100
OG-06	10/09/86		U10	U10	U10	U10	U50	U100
OG-07	10/09/86		U10	U10	U10	U10	U50	U100
PS-02	10/13/86		U10	U10	U10	U10	U50	U100
PS-03	10/13/86		U10	U10	U10	U10	U50	U100
PS-04	10/10/86		U10	U10	U10	U10	U50	U100
SD-01	10/09/86		U10	U10	U10	U10	U50	U100
SD-02	10/07/86		U10	U10	U10	U10	U50	U100
SD-03	10/02/86		U10	U10	U10	U10	U50	U100
SR-01	10/06/86		U10	U10	U10	U10	U50	U100

TABLE B-19. (Continued)

Station	Sampling Date	Rep	2,6-dinitro-toluene	2,4-dinitro-toluene	N-nitroso-di-phenyl-amine	3,3'di-chloro-benzidine
ES-01	10/06/86		U10	U10	U10	U50
ES-02	10/06/86		U10	U10	E16	U50
ES-03	10/06/86		U10	U10	E26	U50
EW-01	10/07/86		U10	U10	57	U50
EW-04	09/30/86		U10	U10	U10	U50
EW-07	09/30/86	1	U10	U10	U10	U50
EW-07	09/30/86	2	U10	U10	U10	U50
EW-07	09/30/86	3	U10	U10	U10	U50
EW-07	09/30/86	Mean	U10	U10	U10	U50
EW-10	10/01/86		U10	U10	U10	U50
EW-11	09/30/86		U10	U10	U10	U50
EW-12	10/01/86		U10	U10	U10	U50
EW-13	10/01/86		U10	U10	U10	U50
EW-14	10/01/86		U10	U10	U10	U50
EW-15	10/01/86		U10	U10	U10	U50
NG-01	10/02/86		U10	U10	U10	U50
NG-02	10/02/86		U10	U10	U10	U50
NG-03	10/02/86		U10	U10	U10	U50
NG-04	10/02/86		U10	U10	U10	U50
NG-05	10/02/86		U10	U10	U10	U50
NG-06	10/08/86		U10	U10	24	U50
NG-07	10/02/86		U10	U10	U10	U50
NG-08	10/02/86		U10	U10	U10	U50
NG-09	10/03/86		U10	U10	U10	U50
NG-10	10/03/86		U10	U10	U10	U50
NG-11	10/03/86		U10	U10	U10	U50
NG-12	10/15/86		U10	U10	U10	U50
NG-13	10/15/86		U10	U10	8	U50
NG-14	10/15/86		U10	U10	U10	U50
NG-15	10/15/86		U10	U10	U10	U50
OG-01	10/09/86		U10	U10	U10	U50
OG-02	10/09/86		U10	U10	U10	U50
OG-03	10/09/86		U10	U10	38	U50
OG-04	10/09/86		U10	U10	29	U50
OG-05	10/09/86		U10	U10	28	U50
OG-06	10/09/86		U10	U10	34	U50
OG-07	10/09/86		U10	U10	15	U50
PS-02	10/13/86		U10	U10	U10	U50
PS-03	10/13/86		U10	U10	U10	U50
PS-04	10/10/86		U10	U10	U10	U50
SD-01	10/09/86		U10	U10	E15	U50
SD-02	10/07/86		U10	U10	U10	U50
SD-03	10/02/86		U10	U10	U10	U50
SR-01	10/06/86		U10	U10	U10	U50

TABLE B-20. CONCENTRATIONS (UG/KG DRY WEIGHT) OF EXTRACTABLE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: MISCELLANEOUS AROMATIC COMPOUNDS

Station	Sampling Date	Rep	2-methyl-naphthalene
ES-01	10/06/86		4
ES-02	10/06/86		6
ES-03	10/06/86		17
EW-01	10/07/86		160
EW-04	09/30/86		5000
EW-07	09/30/86	1	X7900
EW-07	09/30/86	2	3200
EW-07	09/30/86	3	X11000
EW-07	09/30/86	Mean	X7400
EW-10	10/01/86		U10
EW-11	09/30/86		330
EW-12	10/01/86		X310
EW-13	10/01/86		6700
EW-14	10/01/86		6400
EW-15	10/01/86		1100
NG-01	10/02/86		X120
NG-02	10/02/86		U10
NG-03	10/02/86		U10
NG-04	10/02/86		X75
NG-05	10/02/86		X120
NG-06	10/08/86		6
NG-07	10/02/86		U10
NG-08	10/02/86		X82
NG-09	10/03/86		400
NG-10	10/03/86		80
NG-11	10/03/86		190
NG-12	10/15/86		U10
NG-13	10/15/86		U10
NG-14	10/15/86		U10
NG-15	10/15/86		U10
OG-01	10/09/86		80
OG-02	10/09/86		Z71
OG-03	10/09/86		80
OG-04	10/09/86		72
OG-05	10/09/86		61
OG-06	10/09/86		120
OG-07	10/09/86		65
PS-02	10/13/86		3
PS-03	10/13/86		2
PS-04	10/10/86		U10
SD-01	10/09/86		U10
SD-02	10/07/86		U10
SD-03	10/02/86		X120
SR-01	10/06/86		U10
SR-02	10/06/86		6

TABLE B-21. CONCENTRATIONS (UG/KG DRY WEIGHT) OF RESIN ACID COMPOUNDS IN EVERETT HARBOR SEDIMENTS

Station	Sampling Date	Rep	sand-araco-pimaric acid	iso-pimaric acid	dehydro-abietic acid	abietic acid	neo-abietic acid	14-chloro-dehydro-abietic acid
EW-01	10/07/86		14000	U410	10000	E3100	U410	U410
EW-02	09/30/86		1500	3700	14000	7400	U550	1300
EW-03	09/30/86		2600	2200	17000	19000	U650	E1000
EW-04	09/30/86		8800	E5600	83000	52000	U600	3400
EW-05	09/30/86		E660	E660	4200	2300	U500	E310
EW-06	09/30/86		1800	4500	20000	12000	E750	U400
EW-07	09/30/86	1	E360	900	6500	3300	E230	1200
EW-07	09/30/86	2	3800	6200	9300	13000	680	1600
EW-07	09/30/86	Mean	E2100	3600	7900	8200	E460	1400
EW-08	09/30/86		1500	2500	9100	5100	E450	E270
EW-09	09/30/86		U900	E500	2500	U900	U900	900
EW-11	09/30/86		4100	1200	7100	7300	U500	U500
EW-13	10/01/86		6500	E11000	75000	98000	E14000	U800
EW-14	10/01/86		E2500	2300	3800	L1600	E380	U290
EW-15	10/01/86		E200	E330	1200	590	E79	U220
OG-02	10/09/86		E98	E240	1100	760	U190	U190
OG-03	10/09/86		E110	E350	1500	1700	U180	E59
OG-04	10/09/86		E76	U180	960	780	U180	U180
OG-06	10/09/86		E100	E260	1400	1200	U240	E100
OG-07	10/09/86		E43	E85	560	E280	U160	E46
PS-02	10/13/86		U180	U180	E40	U180	U180	U180
PS-03	10/13/86	1	U130	U130	U130	U130	U130	U130
PS-03	10/13/86	2	U130	U130	U130	U130	U130	U130
PS-03	10/13/86	Mean	U130	U130	U130	U130	U130	U130
PS-04	10/10/86		U130	U140	E20	U140	U140	U140
SD-01	10/09/86		U140	U140	E34	U140	U140	U140
SD-02	10/07/86		U150	U150	E150	U150	U150	U150
SR-03	10/06/86		E17	U140	E230	E170	U140	U140
SR-04	10/06/86		U220	E170	640	E450	U220	U220
SR-05	10/06/86		940	1500	3500	2300	E120	U250
SS-02	10/06/86		E51	E210	730	E340	E160	U180
SS-03	10/06/86	1	E34	E130	E180	U170	U170	U170
SS-03	10/06/86	2	E85	E140	E300	U210	U210	U210
SS-03	10/06/86	Mean	E60	E140	E240	U170	U170	U170
SS-03	10/06/86		E60	E140	E240	U170	U170	U170
SS-04	10/06/86		U160	U160	U160	U160	U160	U160
SS-05	10/06/86		U150	U150	E82	U150	U150	U150
SS-06	10/06/86		U150	U150	E82	U150	U150	U150

TABLE B-22. CONCENTRATIONS (UG/KG DRY WEIGHT) OF CHLORINATED PHENOLS AND GUAIACOLS IN EVERETT HARBOR SEDIMENTS

Station	Sampling Date	Rep	2-chloro-phenol	2,4-di-chloro-phenol	2,4,6-tri-chloro-phenol	2,4,5-tri-chloro-phenol	2,3,4,6-tetra-chloro-phenol	penta-chloro-phenol
EW-01	10/07/86		31	320	290	88	120	85
EW-02	09/30/86		U44	300	240	120	68	U44
EW-03	09/30/86		44	67	48	U13	U13	E31
EW-04	09/30/86		160	91	79	71	78	E460
EW-05	09/30/86		U10	50	44	10	30	E180
EW-06	09/30/86		25	44	27	12	U8	E43
EW-07	09/30/86	1	U5	32	18	9	U5	E13
EW-07	09/30/86	2	44	22	19	E8	U12	E11
EW-07	09/30/86	Mean	L24	27	18	E8	U5	E12
EW-08	09/30/86		U10	27	21	E8	U10	E13
EW-09	09/30/86		22	52	41	23	U18	E91
EW-11	09/30/86		U10	26	18	E8	19	E12
EW-13	10/01/86		U63	91	E44	U63	U63	E27
EW-14	10/01/86		U6	24	9	E4	U6	E16
EW-15	10/01/86		U4	7	7	E2	U4	13
OG-02	10/09/86		10	7	E3	6	U4	E5
OG-03	10/09/86		U4	12	5	4	U4	E4
OG-04	10/09/86		U4	6	E2	E2	U4	E3
OG-06	10/09/86		U4	9	U4	E3	U4	E4
OG-07	10/09/86		U3	4	E2	E1	U3	E2
PS-02	10/13/86	1	U3	U3	E2	U3	U3	U3
PS-02	10/13/86	2	U3	U3	E2	U3	U3	U3
PS-02	10/13/86	Mean	U3	U3	E2	U3	U3	U3
PS-03	10/13/86	1	U3	U3	U3	U3	U3	U3
PS-03	10/13/86	2	U3	U3	3	3	U3	U3
PS-03	10/13/86	Mean	U3	U3	L3	L3	U3	U3
PS-04	10/10/86		U3	U3	U3	U3	U3	U3
SD-01	10/09/86		U3	U3	U3	U3	U3	U3
SD-02	10/07/86		36	9	E6	U6	U6	E17
SR-03	10/06/86		U2	U2	U2	U2	U2	U2
SR-04	10/06/86		8	2	U4	U4	U4	E3
SR-05	10/06/86		U5	U5	U5	U5	U5	E3
SS-02	10/06/86		11	U3	U3	U3	U3	10
SS-03	10/06/86	1	U6	6	6	U6	E3	E3
SS-03	10/06/86	2	U3	4	E3	U3	U3	11
SS-03	10/06/86	3	U6	6	U6	E2	U6	U6
SS-03	10/06/86	4	U4	4	E3	U4	E2	U4
SS-03	10/06/86	Mean	U3	5	L4	L2	L2	L6
SS-04	10/06/86		U3	U3	12	U3	U3	U3
SS-05	10/06/86		E1	U3	U3	U3	U3	U3
SS-06	10/06/86		U3	U3	U3	U3	U3	U3

TABLE B-23. CONCENTRATIONS (UG/KG DRY WEIGHT) OF EXTRACTABLE ORGANIC COMPOUNDS IN EVERETT HARBOR SEDIMENTS: GROUP SUMS

Station	Sampling Date	Rep	low molecular weight aromatic hydro-carbons	high molecular weight aromatic hydro-carbons	total benzo-fluoran-thenes
ES-01	10/06/86		L57	180	32
ES-02	10/06/86		L49	160	24
ES-03	10/06/86		Z180	L280	40
EW-01	10/07/86		Z1800	2500	320
EW-04	09/30/86		25000	8800	1100
EW-07	09/30/86	1	24000	5000	530
EW-07	09/30/86	2	14000	4700	390
EW-07	09/30/86	3	30000	6700	760
EW-07	09/30/86	Mean	E23000	5500	560
EW-10	10/01/86		5200	6500	820
EW-11	09/30/86		2400	1900	250
EW-12	10/01/86		1400	1000	170
EW-13	10/01/86		24000	11000	1100
EW-14	10/01/86		28000	23000	4100
EW-15	10/01/86		4900	3000	340
NG-01	10/02/86		L200	L140	19
NG-02	10/02/86		L110	L72	10
NG-03	10/02/86		L140	L76	8
NG-04	10/02/86		L220	L150	19
NG-05	10/02/86		L300	L160	21
NG-06	10/08/86		L130	400	72
NG-07	10/02/86		110	470	110
NG-08	10/02/86		L310	440	82
NG-09	10/03/86		Z4100	Z9000	2000
NG-10	10/03/86		Z1200	Z2800	460
NG-11	10/03/86		Z3500	Z8700	1600
NG-12	10/15/86		L47	L83	11
NG-13	10/15/86		L50	L88	11
NG-14	10/15/86		L460	Z840	70
NG-15	10/15/86		L55	L75	10
OG-01	10/09/86		Z840	660	74
OG-02	10/09/86		Z890	Z920	140
OG-03	10/09/86		Z820	L610	65
OG-04	10/09/86		Z800	690	79
OG-05	10/09/86		Z490	370	40
OG-06	10/09/86		Z600	L470	55
OG-07	10/09/86		Z800	730	78
PS-02	10/13/86		L39	L48	5
PS-03	10/13/86		L42	L43	U10
PS-04	10/10/86		L36	L36	5
SD-01	10/09/86		L46	L58	U10
SD-02	10/07/86		L180	L210	26

TABLE B-24. CONCENTRATIONS (UG/KG DRY WEIGHT) OF TENTATIVELY IDENTIFIED COMPOUNDS IN EVERETT HARBOR SEDIMENTS

Station	Sampling Date	Rep	cymene	1,2,4-tri-thiolane	base peak m/z 181, isomer 1	base peak m/z 181, isomer 2	di-benzo-thio-phene	hexa-decenoic acid methyl ester
ES-01	10/06/86		E2.2	U	E37	B	U	E182
ES-02	10/06/86		E2.2	E8.4	B	E3.7	U	E350
ES-03	10/06/86		E15	E22	E18	E4.9	U	E590
EW-01	10/07/86		E340	E1400	E790	E790	U	E580
EW-04	09/30/86		E2900	E5800	E12000	E6500	U	E3200
EW-07	09/30/86	1	E210	E610	E1600	E1500	E110	E360
EW-07	09/30/86	2	E220	E370	E1600	E930	E86	E470
EW-07	09/30/86	3	E260	E970	E3600	E2000	E120	E380
EW-07	09/30/86	Mean	E230	E650	E2300	E1500	E100	E400
EW-10	10/01/86		E64	E1600	E1100	E860	E33	E730
EW-11	09/30/86		E400	E590	E1000	E360	U	E200
EW-12	10/01/86		E9.9	E5.7	E380	E200	E10	E880
EW-13	10/01/86		E1000	E510	E810	E370	E86	E830
EW-14	10/01/86		E72	E180	E320	E270	E280	E71
EW-15	10/01/86		E120	E380	E750	E460	E43	E740
NG-01	10/02/86		U	U	E130	E69	U	E950
NG-02	10/02/86		E0.5	E5.3	E41	E20	U	E640
NG-03	10/02/86		U	U	E22	E11	U	E910
NG-04	10/02/86		E0.7	U	E12	E5.9	U	E1100
NG-05	10/02/86		U	U	E20	E11	U	E230
NG-06	10/08/86		E5.5	U	E24	E14	E2.6	E360
NG-07	10/02/86		U	U	E9.1	E4.3	U	E41
NG-08	10/02/86		E0.9	U	E19	E12	U	E56
NG-09	10/03/86		E300	E180	E96	E41	E79	E300
NG-10	10/03/86		E6.1	E4.3	E17	E11	E18	E150
NG-11	10/03/86		E3.0	E37	E8.4	E18	E120	E55
NG-12	10/15/86		U	U	E6.1	E3.1	U	E180
NG-13	10/15/86		U	U	E18	E9.9	U	E320
NG-14	10/15/86		U	U	U	U	E22	E350
NG-15	10/15/86		U	U	U	E5.8	U	E210
OG-01	10/09/86		E300	E160	E580	E350	E14	E330
OG-02	10/09/86		E280	E8.5	E340	E180	E8.6	E32
OG-03	10/09/86		E350	E71	E390	E210	E12	E330
OG-04	10/09/86		E240	E58	E300	E130	E6.2	E330
OG-05	10/09/86		E150	E39	E150	E82	U	E120
OG-06	10/09/86		E250	E44	E310	E170	E5.9	E380
OG-07	10/09/86		E140	E27	E330	E220	E9.4	E390
PS-02	10/13/86		U	U	U	U	U	E330
PS-03	10/13/86		U	U	B	B	U	E380
PS-04	10/10/86		U	U	B	B	U	E330
SD-01	10/09/86		E0.5	U	B	B	U	E180
SD-02	10/07/86		E28	E2.3	E160	E87	U	E290
SD-03	10/02/86		E3.4	E4.0	E260	E93	U	E77

TABLE B-24. (Continued)

Station	Sampling Date	Rep	hexa-decanoic acid methyl ester	hexa-decanoic acid	diter-penoid hydro-carbon	diter-penoid alcohol	retene	1-methyl-pyrene
ES-01	10/06/86		E340	E54	E19	E12	E6.1	U
ES-02	10/06/86		E660	U	E6.1	E12	E3.0	U
ES-03	10/06/86		E990	B	E100	E130	E56	U
EW-01	10/07/86		E1200	U	E600	E1300	E190	U
EW-04	09/30/86		E4300	U	E23000	U	E3100	U
EW-07	09/30/86	1	E660	E1600	E560	E140	E560	U
EW-07	09/30/86	2	E800	B	E440	E610	E840	E30
EW-07	09/30/86	3	E1400	E1200	E410	E1700	E1400	U
EW-07	09/30/86	Mean	E950	E1400	E470	E820	E930	E30
EW-10	10/01/86		E2200	E2300	E490	E1100	U	U
EW-11	09/30/86		E700	E1000	E800	E8600	E62	U
EW-12	10/01/86		E1100	B	E200	E31	E76	E8.1
EW-13	10/01/86		E1500	U	E1500	U	E2900	U
EW-14	10/01/86		E210	U	E1700	E1200	U	U
EW-15	10/01/86		E1900	E600	E360	E200	E160	E26
NG-01	10/02/86		E990	B	E9.5	E4.3	E7.0	E1.6
NG-02	10/02/86		E830	U	U	E1.4	E7.0	U
NG-03	10/02/86		E430	B	U	U	E3.0	U
NG-04	10/02/86		E1100	U	U	U	E3.5	E0.9
NG-05	10/02/86		E280	E42	E1.7	E1.2	E5.4	E1.9
NG-06	10/08/86		E360	E36	E77	U	E9.8	E3.8
NG-07	10/02/86		E92	E64	U	U	U	E6.5
NG-08	10/02/86		E160	E59	E2.7	E25	U	U
NG-09	10/03/86		E440	B	E14	E23	E140	E170
NG-10	10/03/86		E350	E180	E9.8	E10	U	E36
NG-11	10/03/86		E100	E380	E120	E1000	U	E240
NG-12	10/15/86		E200	U	U	U	E0.8	E0.4
NG-13	10/15/86		E580	E80	U	E0.9	E4.7	U
NG-14	10/15/86		E550	B	U	U	U	E12
NG-15	10/15/86		E450	E110	U	E1.5	E3.1	U
OG-01	10/09/86		E470	E520	E230	E26	E60	E5.7
OG-02	10/09/86		E59	E54	E61	E7.3	E24	E8.4
OG-03	10/09/86		E440	E320	E120	E17	E33	E6.7
OG-04	10/09/86		E260	E90	E110	E20	E60	E3.2
OG-05	10/09/86		E150	E120	E52	E14	E40	U
OG-06	10/09/86		E380	B	E140	E17	E56	U
OG-07	10/09/86		E470	B	E40	E11	E57	E7.6
PS-02	10/13/86		E380	B	U	E3.1	E1.2	U
PS-03	10/13/86		E480	E35	U	E1.8	E1.6	U
PS-04	10/10/86		E440	B	U	E1.2	U	U
SD-01	10/09/86		E190	U	U	E0.4	E1.3	U
SD-02	10/07/86		E260	B	E12	E4.0	E32	E1.7
SD-03	10/02/86		E230	E130	E32	E31	E27	E3.7
SR-01	10/06/86		E590	B	E1.8	E1.8	E2.9	U

TABLE B-24. (Continued)

Station	Sampling Date	Rep	alkanol	chol-esterol	camp-esterol
ES-01	10/06/86		E88	E18	U
ES-02	10/06/86		E230	E35	U
ES-03	10/06/86		E340	E120	U
EW-01	10/07/86		E380	E120	E81
EW-04	09/30/86		E2200	E630	E1100
EW-07	09/30/86	1	E250	E71	E97
EW-07	09/30/86	2	E430	E56	E110
EW-07	09/30/86	3	E680	E68	E88
EW-07	09/30/86	Mean	E450	E65	E98
EW-10	10/01/86		E1200	E120	E25
EW-11	09/30/86		E930	E45	E720
EW-12	10/01/86		E580	E26	E73
EW-13	10/01/86		E1000	E130	E360
EW-14	10/01/86		E300	E65	U
EW-15	10/01/86		E540	E77	E74
NG-01	10/02/86		E350	E22	U
NG-02	10/02/86		E390	E13	U
NG-03	10/02/86		E470	E26	U
NG-04	10/02/86		E390	E20	U
NG-05	10/02/86		E390	E86	U
NG-06	10/08/86		E150	E160	U
NG-07	10/02/86		E210	E12	U
NG-08	10/02/86		E270	E32	U
NG-09	10/03/86		E460	E280	U
NG-10	10/03/86		E62	E150	U
NG-11	10/03/86		E27	E160	U
NG-12	10/15/86		U	E6.1	U
NG-13	10/15/86		U	E57	U
NG-14	10/15/86		U	E260	U
NG-15	10/15/86		U	E52	E3.9
OG-01	10/09/86		E390	E70	E170
OG-02	10/09/86		E83	E28	E8.5
OG-03	10/09/86		E360	E140	E99
OG-04	10/09/86		E280	E93	E140
OG-05	10/09/86		E130	E13	E37
OG-06	10/09/86		E290	E54	E20
OG-07	10/09/86		E190	E4.1	E63
PS-02	10/13/86		U	E47	U
PS-03	10/13/86		U	E19	U
PS-04	10/10/86		U	E20	U
SD-01	10/09/86		U	E0.7	U
SD-02	10/07/86		E85	E60	U
SD-03	10/02/86		E520	E31	U
SR-01	10/06/86		U	E16	U
SR-02	10/06/86		U	E12	U
SR-03	10/06/86		E71	E6.8	U
SR-04	10/06/86		E260	E65	E7.9

TABLE B-25. CONCENTRATIONS (UG/KG DRY WEIGHT) OF PESTICIDES AND TOTAL POLYCHLORINATED BIPHENYLS IN EVERETT HARBOR SEDIMENTS

Station	Sampling Date	Rep	p,p'-DDE	p,p'-DDD	p,p'-DDT	aldrin	dieldrin
ES-01	10/06/86		U10	U10	U1.0	U5.0	U10
ES-02	10/06/86		U1.0	U1.0	U1.0	U0.50	U1.0
ES-03	10/06/86		U10	U10	U10	U5.0	U10
EW-01	10/07/86		U100	U100	U100	U50	U100
EW-04	09/30/86		U200	U200	U200	U100	U200
EW-07	09/30/86	1	U10	U10	U10	U5.0	U10
EW-07	09/30/86	2	U10	U10	U10	U5.0	U10
EW-07	09/30/86	Mean	U10	U10	U10	U5.0	U10
EW-10	10/01/86		U10	U10	U10	U5.0	U10
EW-11	09/30/86		U5.0	U100	U10	U5.0	U5.0
EW-12	10/01/86		U10	U1.0	U1.0	U5.0	U1.0
EW-13	10/01/86	1	U10	U10	U10	U5.0	U10
EW-13	10/01/86	2	U10	U10	U10	U5.0	U10
EW-13	10/01/86	Mean	U10	U10	U10	U5.0	U10
EW-14	10/01/86		U100	U100	U100	U50	U100
EW-15	10/01/86		U100	U100	U100	U50	U100
NG-01	10/02/86		U1.0	U1.0	U1.0	U0.50	U1.0
NG-02	10/02/86		U1.0	U1.0	U1.0	U0.50	U1.0
NG-03	10/02/86		U1.0	U1.0	U1.0	U0.50	U1.0
NG-04	10/02/86		U1.0	U1.0	U1.0	U0.50	U1.0
NG-05	10/02/86		U1.0	U1.0	U1.0	U0.50	U1.0
NG-06	10/08/86		U10	U10	U10	U5.0	U10
NG-07	10/02/86		U1.0	U1.0	U1.0	U0.50	U1.0
NG-08	10/02/86		U1.0	U1.0	U1.0	U5.0	U1.0
NG-09	10/03/86		U100	U100	U100	U50	U100
NG-10	10/03/86		U10	U10	U10	U5.0	U10
NG-11	10/03/86		U10	U10	U10	U5.0	U10
NG-12	10/15/86		U1.0	U1.0	U1.0	U0.50	U1.0
NG-13	10/15/86		U1.0	U1.0	U1.0	U0.50	U1.0
NG-14	10/15/86		U1.0	U1.0	U1.0	U5.0	U1.0
NG-15	10/15/86		U1.0	U1.0	U1.0	U0.5	U1.0
OG-01	10/09/86		U10	U10	U10	U5.0	U10
OG-02	10/09/86		U10	U10	U10	U5.0	U10
OG-03	10/09/86		U10	U10	U10	U5.0	U10
OG-04	10/09/86		U10	U10	U10	U5.0	U10
OG-05	10/09/86		U10	U10	U10	U5.0	U10
OG-06	10/09/86		U1.0	U1.0	U1.0	U5.0	U1.0
OG-07	10/09/86		U10	U10	U10	U5.0	U10
PS-02	10/13/86		U10	U10	U10	U5.0	U10
PS-03	10/13/86		U1.0	U1.0	U1.0	U0.50	U1.0
PS-04	10/10/86		U1.0	U1.0	U1.0	U0.50	U1.0
SD-01	10/09/86		U1.0	U1.0	U1.0	U0.50	U1.0

TABLE B-25. (Continued)

Station	Sampling Date	Rep	alpha-HCH	beta-HCH	delta-HCH	gamma-HCH (lindane)	chlordane
ES-01	10/06/86		U5.0	U5.0	U5.0	U5.0	U50
ES-02	10/06/86		U0.50	U0.50	U0.50	U0.50	U5.0
ES-03	10/06/86		U5.0	U5.0	U5.0	U5.0	U50
EW-01	10/07/86		U50	U50	U50	U50	U500
EW-04	09/30/86		U100	U100	U100	U100	U1000
EW-07	09/30/86	1	U50	U50	U50	U50	U50
EW-07	09/30/86	2	U50	U50	U5.0	U50	U50
EW-07	09/30/86	Mean	U50	U50	U5.0	U50	U50
EW-10	10/01/86		U50	U50	U5.0	U50	U50
EW-11	09/30/86		U5.0	U5.0	U5.0	U5.0	U50
EW-12	10/01/86		U5.0	U5.0	U5.0	U5.0	U5.0
EW-13	10/01/86	1	U50	U5.0	U5.0	U5.0	U50
EW-13	10/01/86	2	U50	U50	U50	U50	U50
EW-13	10/01/86	Mean	U50	U5.0	U5.0	U5.0	U50
EW-14	10/01/86		U50	U50	U50	U50	U500
EW-15	10/01/86		U50	U50	U50	U50	U500
NG-01	10/02/86		U0.50	U0.50	U0.50	U0.50	U5.0
NG-02	10/02/86		U0.50	U0.50	U0.50	U0.50	U5.0
NG-03	10/02/86		U0.50	U0.50	U0.50	U0.50	U5.0
NG-04	10/02/86		U5.0	U0.50	U0.50	1	U5.0
NG-05	10/02/86		U5.0	U0.50	U0.50	U0.50	U5.0
NG-06	10/08/86		U5.0	U5.0	U5.0	U5.0	U50
NG-07	10/02/86		U0.50	U0.50	U0.50	U0.50	U5.0
NG-08	10/02/86		U5.0	U5.0	U5.0	U5.0	U5.0
NG-09	10/03/86		U50	U50	U50	U50	U500
NG-10	10/03/86		U5.0	U5.0	U5.0	U5.0	U50
NG-11	10/03/86		U5.0	U5.0	U5.0	U5.0	U50
NG-12	10/15/86		U0.50	U0.50	U0.50	U0.50	U5.0
NG-13	10/15/86		U5.0	U5.0	U0.50	U5.0	U5.0
NG-14	10/15/86		U5.0	U5.0	U5.0	U5.0	U5.0
NG-15	10/15/86		U5.0	U0.5	U0.5	U0.5	U5.0
OG-01	10/09/86		U5.0	U5.0	U5.0	U5.0	U50
OG-02	10/09/86		U50	U50	U5.0	U50	U50
OG-03	10/09/86		U5.0	U5.0	U5.0	U5.0	U50
OG-04	10/09/86		U5.0	U5.0	U5.0	U5.0	U50
OG-05	10/09/86		U5.0	U5.0	U5.0	U5.0	U50
OG-06	10/09/86		U5.0	U5.0	U5.0	U5.0	U50
OG-07	10/09/86		U5.0	U5.0	U5.0	U5.0	U50
PS-02	10/13/86		U50	U50	U5.0	U50	U50
PS-03	10/13/86		U0.50	U0.50	U0.50	U0.50	U5.0
PS-04	10/10/86		U0.50	U0.50	U0.50	U0.50	U5.0

TABLE B-25. (Continued)

Station	Sampling Date	Rep	alpha-endo-sulfan	beta-endo-sulfan	endo-sulfan sulfate	endrin	hepta-chlor	hepta-chlor epoxide
ES-01	10/06/86		U5.0	U1.0	U1.0	U10	U5.0	U5.0
ES-02	10/06/86		U0.50	U1.0	U1.0	U1.0	U0.50	U0.50
ES-03	10/06/86		U5.0	U10	U10	U10	U5.0	U5.0
EW-01	10/07/86		U50	U100	U100	U100	U50	U50
EW-04	09/30/86		U100	U200	U200	U200	U100	U100
EW-07	09/30/86	1	U5.0	U10	U10	U10	U50	U5.0
EW-07	09/30/86	2	U5.0	U10	U10	U10	U50	U5.0
EW-07	09/30/86	Mean	U5.0	U10	U10	U10	U50	U5.0
EW-10	10/01/86		U5.0	U10	U10	U10	U50	U5.0
EW-11	09/30/86		U5.0	U100	U10	U10	U5.0	U5.0
EW-12	10/01/86		U5.0	U10	U1.0	U10	U5.0	U5.0
EW-13	10/01/86	1	U5.0	U10	U10	U10	U5.0	U5.0
EW-13	10/01/86	2	U5.0	U10	U10	U10	U50	U5.0
EW-13	10/01/86	Mean	U5.0	U10	U10	U10	U5.0	U5.0
EW-14	10/01/86		U50	U100	U100	U100	U50	U50
EW-15	10/01/86		U50	U100	U100	U100	U50	U50
NG-01	10/02/86		U0.50	U1.0	U1.0	U1.0	U0.50	U0.50
NG-02	10/02/86		U0.50	U1.0	U1.0	U1.0	U0.50	U0.50
NG-03	10/02/86		U0.50	U1.0	U1.0	U1.0	U0.50	U0.50
NG-04	10/02/86		U0.50	U1.0	U1.0	U1.0	U0.50	U0.50
NG-05	10/02/86		U0.50	U1.0	U1.0	U1.0	U0.50	U0.50
NG-06	10/08/86		U5.0	U10	U10	U10	U5.0	U5.0
NG-07	10/02/86		U0.50	U1.0	U1.0	U1.0	U0.50	U0.50
NG-08	10/02/86		U0.50	U1.0	U1.0	U1.0	U5.0	U0.50
NG-09	10/03/86		U50	U100	U100	U100	U50	U50
NG-10	10/03/86		U5.0	U10	U10	U10	U5.0	U5.0
NG-11	10/03/86		U5.0	U10	U10	U10	U5.0	U5.0
NG-12	10/15/86		U0.50	U1.0	U1.0	U1.0	U0.50	U0.50
NG-13	10/15/86		U0.50	U1.0	U1.0	U1.0	U5.0	U0.50
NG-14	10/15/86		U0.5	U1.0	U1.0	U1.0	U5.0	U0.5
NG-15	10/15/86		U0.5	U1.0	U1.0	U1.0	U0.5	U0.5
OG-01	10/09/86		U5.0	U10	U10	U10	U5.0	U5.0
OG-02	10/09/86		U5.0	U10	U10	U10	U5.0	U5.0
OG-03	10/09/86		U5.0	U10	U10	U10	U5.0	U5.0
OG-04	10/09/86		U5.0	U10	U10	U10	U5.0	U5.0
OG-05	10/09/86		U5.0	U10	U10	U10	U5.0	U5.0
OG-06	10/09/86		U5.0	U1.0	U1.0	U10	U5.0	U5.0
OG-07	10/09/86		U5.0	U10	U1.0	U10	U5.0	U5.0
PS-02	10/13/86		U5.0	U10	U10	U10	U50	U5.0
PS-03	10/13/86		U0.50	U1.0	U1.0	U1.0	U0.50	U0.50
PS-04	10/10/86		U0.50	U1.0	U1.0	U1.0	U0.50	U0.50
SD-01	10/09/86		U0.50	U1.0	U1.0	U1.0	U0.50	U0.50

TABLE B-25. (Continued)

Station	Sampling Date	Rep	toxaphene	endrin ketone	methoxychlor	total PCBs
ES-01	10/06/86		U100	U1.0	U5.0	U5.0
ES-02	10/06/86		U10	U1.0	U5.0	U5.0
ES-03	10/06/86		U100	U10	U50	U5.0
EW-01	10/07/86		U1000	U100	U500	U5.0
EW-04	09/30/86		U2000	U200	U1000	E9600
EW-07	09/30/86	1	U100	U10	U50	E83
EW-07	09/30/86	2	U100	U10	U50	E90
EW-07	09/30/86	Mean	U100	U10	U50	E86
EW-10	10/01/86		U100	U10	U50	E13
EW-11	09/30/86		U1000	U10	U50	U5.0
EW-12	10/01/86		U10	U10	U5.0	U5.0
EW-13	10/01/86	1	U100	U10	U50	NR
EW-13	10/01/86	2	U100	U10	U50	NR
EW-13	10/01/86	Mean	U100	U10	U50	U5.0
EW-14	10/01/86		U1000	U100	U500	U50
EW-15	10/01/86		U1000	U100	U500	U5.0
NG-01	10/02/86		U10	U1.0	U5.0	U1
NG-02	10/02/86		U10	U1.0	U5.0	U5.0
NG-03	10/02/86		U10	U1.0	U5.0	U5.0
NG-04	10/02/86		U10	U1.0	U5.0	U5.0
NG-05	10/02/86		U10	U1.0	U5.0	U1
NG-06	10/08/86	1	NR	NR	NR	U5.0
NG-06	10/08/86	2	NR	NR	NR	U5.0
NG-06	10/08/86	Mean	U100	U10	U50	U5.0
NG-07	10/02/86		U10	U1.0	U5.0	U5.0
NG-08	10/02/86		U10	U1.0	U5.0	E11
NG-09	10/03/86		U1000	U100	U500	E5500
NG-10	10/03/86		U100	U10	U50	U50
NG-11	10/03/86		U100	U10	U50	U50
NG-12	10/15/86		U10	U1.0	U5.0	U50
NG-13	10/15/86		U10	U1.0	U5.0	U50
NG-14	10/15/86		U10	U1.0	U5.0	U50
NG-15	10/15/86		U10	U1.0	U5.0	E41
OG-01	10/09/86		U100	U10	U50	U5.0
OG-02	10/09/86	1	NR	NR	NR	U5.0
OG-02	10/09/86	2	NR	NR	NR	U5.0
OG-02	10/09/86	Mean	U100	U10	U50	U5.0
OG-03	10/09/86		U100	U1.0	U5.0	U5.0
OG-04	10/09/86		U100	U10	U50	U50
OG-05	10/09/86		U100	U10	U50	U50
OG-06	10/09/86		U10	U1.0	U5.0	U50
OG-07	10/09/86		U100	U1.0	U5.0	U50
PS-02	10/13/86		U100	U10	U50	U50
PS-03	10/13/86		U10	U1.0	U5.0	U50
PS-04	10/10/86		U10	U1.0	U5.0	U50
SD-01	10/09/86		U10	U1.0	U5.0	U5.0
SD-02	10/07/86		U10	U1.0	U5.0	U5.0

TABLE B-26. CONVENTIONAL VARIABLES IN EVERETT HARBOR SEDIMENTS: TOTAL SOLIDS, TOTAL ORGANIC CARBON, TOTAL NITROGEN, AND SULFIDE

Station	Sampling Date	Rep	percent total solids (wet wt)	percent total organic carbon (dry wt)	percent nitrogen (dry wt)	sulfide (mg/kg dry wt)
ES-01	10/06/86		73.6	0.54	0.030	10
ES-02	10/06/86		74.9	0.73	0.039	10
ES-03	10/06/86		63.4	1.43	0.099	U5
EW-01	10/07/86		25.8	10.7	0.59	U5
EW-02	09/30/86		23.0	8.69	0.51	11200
EW-03	09/30/86	1	22.0	10.2	0.59	9500
EW-03	09/30/86	2	22.0	NR	NR	NR
EW-03	09/30/86	Mean	22.0	10.2	0.59	9500
EW-04	09/30/86		27.2	29.4	0.50	7600
EW-05	09/30/86	1	31.7	12.0	0.35	2700
EW-05	09/30/86	2	32.1	NR	NR	NR
EW-05	09/30/86	Mean	31.9	12.0	0.35	2700
EW-06	09/30/86		33.0	11.2	0.36	420
EW-07	09/30/86	1	41.8	6.19	0.22	930
EW-07	09/30/86	2	46.6	6.20	0.23	1400
EW-07	09/30/86	3	45.0	5.92	0.26	NR
EW-07	09/30/86	Mean	44.5	6.10	0.24	1200
EW-08	09/30/86		32.0	13.2	0.35	2800
EW-09	09/30/86	1	23.9	14.6	0.47	2300
EW-09	09/30/86	2	NR	14.2	0.47	NR
EW-09	09/30/86	Mean	23.9	14.4	0.47	2300
EW-10	10/01/86	1	38.2	11.8	0.35	2900
EW-10	10/01/86	2	38.4	NR	NR	NR
EW-10	10/01/86	Mean	38.3	11.8	0.35	2900
EW-11	09/30/86	1	36.9	9.54	0.26	2100
EW-11	09/30/86	2	39.4	NR	NR	NR
EW-11	09/30/86	Mean	38.2	9.54	0.26	2100
EW-12	10/01/86		71.3	2.23	0.048	240
EW-13	10/01/86		28.3	22.7	0.26	1200
EW-14	10/01/86	1	49.9	4.66	0.25	700
EW-14	10/01/86	2	72.0	NR	NR	NR
EW-14	10/01/86	Mean	61.0	4.66	0.25	700
EW-15	10/01/86	1	58.8	4.35	0.14	370
EW-15	10/01/86	2	59.0	NR	NR	NR
EW-15	10/01/86	Mean	58.9	4.35	0.14	370
NG-01	10/02/86		79.0	0.20	0.013	40
NG-02	10/02/86		76.5	0.18	0.010	67
NG-03	10/02/86		79.5	0.19	0.014	18
NG-04	10/02/86		79.7	0.28	0.016	33
NG-05	10/02/86	1	78.5	0.67	0.029	20
NG-05	10/02/86	2	NR	0.64	0.030	NR
NG-05	10/02/86	Mean	78.5	0.66	0.030	20
NG-06	10/08/86		79.9	0.39	0.020	6

TABLE B-26. (Continued)

Station	Sampling Date	Rep	percent total solids (wet wt)	percent total organic carbon (dry wt)	percent nitrogen (dry wt)	sulfide (mg/kg dry wt)
SD-03	10/02/86	Mean	60.9	1.98	0.090	234
SR-01	10/06/86		83.5	0.26	0.021	U5
SR-02	10/06/86		78.2	0.29	0.021	U5
SR-03	10/06/86		78.4	0.43	0.028	10
SR-04	10/06/86		56.1	2.33	0.14	64
SR-05	10/06/86		48.8	3.85	0.20	33
SR-06	10/06/86	1	74.0	0.19	0.013	10
SR-06	10/06/86	2	76.6	NR	NR	NR
SR-06	10/06/86	3	76.8	NR	NR	NR
SR-06	10/06/86	Mean	75.8	0.19	0.013	10
SR-07	10/03/86	1	46.1	3.22	0.22	600
SR-07	10/03/86	2	46.5	3.26	0.21	NR
SR-07	10/03/86	Mean	46.3	3.24	0.22	600
SR-08	10/03/86		74.7	1.71	0.070	90
SS-01	10/06/86		83.5	0.43	0.025	U5
SS-02	10/06/86		70.9	0.79	0.056	10
SS-03	10/06/86	1	68.7	1.58	0.14	18
SS-03	10/06/86	2	69.1	1.43	0.073	10
SS-03	10/06/86	3	68.1	1.52	0.093	NR
SS-03	10/06/86	4	NR	1.56	0.094	NR
SS-03	10/06/86	5	NR	1.56	0.091	NR
SS-03	10/06/86	Mean	68.6	1.51	0.098	14
SS-04	10/06/86		82.2	0.24	0.014	10
SS-05	10/06/86		79.2	0.35	0.024	96
SS-06	10/06/86		75.8	0.79	0.046	16

NR = Replicate analysis for this compound was not performed in this sample.

TABLE B-27. (Continued)

Station	Sampling Date	Rep	percent Rocks	percent Sand	percent Silt	percent Clay
NG-12	10/15/86	Mean	6.1	90.6	0.6	2.8
NG-13	10/15/86		6.3	90.2	0.4	3.1
NG-14	10/15/86		24.5	72.2	0.5	3.0
NG-15	10/15/86		45.4	49.0	1.4	4.2
OG-01	10/09/86	1	1.8	62.5	12.1	23.5
OG-01	10/09/86	2	0.6	66.5	15.6	17.2
OG-01	10/09/86	Mean	1.2	64.5	13.8	20.4
OG-02	10/09/86	1	0.6	72.7	13.4	13.2
OG-02	10/09/86	2	1.1	61.7	16.9	20.4
OG-02	10/09/86	Mean	0.8	67.2	15.2	16.8
OG-03	10/09/86	1	0.2	67.4	15.0	17.3
OG-03	10/09/86	2	0.3	71.5	11.3	17.0
OG-03	10/09/86	Mean	0.2	69.4	13.2	17.2
OG-04	10/09/86	1	1.5	67.3	14.0	17.1
OG-04	10/09/86	2	1.3	67.3	15.1	16.5
OG-04	10/09/86	Mean	1.4	67.3	14.6	16.8
OG-05	10/09/86	1	0.3	62.8	18.6	18.1
OG-05	10/09/86	2	1.8	64.0	16.2	18.1
OG-05	10/09/86	Mean	1.0	63.4	17.4	18.1
OG-06	10/09/86	1	0.4	45.5	27.0	27.1
OG-06	10/09/86	2	0.9	40.3	23.1	35.7
OG-06	10/09/86	Mean	0.6	42.9	25.0	31.4
OG-07	10/09/86	1	0.3	88.9	2.1	8.8
OG-07	10/09/86	2	0.2	85.7	6.2	7.9
OG-07	10/09/86	Mean	0.2	87.3	4.2	8.4
PS-02	10/13/86		0.1	88.4	2.3	9.2
PS-03	10/13/86		0.1	91.9	1.2	6.8
PS-04	10/10/86		1.2	91.5	0.7	6.7
SD-01	10/09/86		12.3	83.1	0.4	4.2
SD-02	10/07/86		0.0	88.5	5.7	5.8
SD-03	10/02/86	1	0.0	48.3	31.0	20.6
SD-03	10/02/86	2	0.0	47.4	31.8	20.8
SD-03	10/02/86	Mean	0.0	47.8	31.4	20.7
SR-01	10/06/86		29.7	66.2	1.0	3.1
SR-02	10/06/86		0.8	94.5	1.3	3.3
SR-03	10/06/86		2.1	88.9	4.9	4.1
SR-04	10/06/86		0.3	38.3	42.7	18.8
SR-05	10/06/86		0.8	34.5	38.2	26.5
SR-06	10/06/86	1	0.1	92.9	1.2	5.9
SR-06	10/06/86	2	0.2	94.0	3.0	2.8
SR-06	10/06/86	3	0.1	97.5	0.3	2.2
SR-06	10/06/86	Mean	0.1	94.8	1.5	3.6
SR-07	10/03/86	1	0.0	4.3	56.5	39.2
SR-07	10/03/86	2	0.4	4.5	61.0	34.1
SR-07	10/03/86	Mean	0.2	4.4	58.8	36.6
SR-08	10/03/86		5.3	72.6	13.2	8.9
SS-01	10/06/86		0.0	90.5	4.6	4.9

TABLE B-28. CONCENTRATIONS (MG/KG WET WEIGHT) OF MERCURY IN EVERETT HARBOR FISH AND CRAB TISSUE

Station	Sample	Sampling Date	Rep	Mercury
EW-91	492 -M[a]	08/28/86		E0.009
EW-91	503 -M	08/28/86		E0.003
EW-91	514 -M	08/28/86		E0.016
EW-91	518 -M	08/29/86	1	E0.011
EW-91	518 -M	08/29/86	2	E0.011
EW-91	518 -M	08/29/86	Mean	E0.011
EW-91	527 -M	08/29/86		E0.009
EW-91	CRAB[b]	NA	1	E0.062
EW-91	CRAB	NA	2	E0.065
EW-91	CRAB	NA	Mean	E0.064
EW-91	CRAB2	NA		E0.082
EW-91	CRAB3	NA		E0.057
EW-92	311 -M	08/27/86		E0.034
EW-92	318 -M	08/27/86		E0.066
EW-92	325 -M	08/27/86		E0.046
EW-92	340 -M	08/27/86		E0.038
EW-92	350 -M	08/27/86		E0.019
EW-92	CRAB	NA		E0.132
NG-91	2 -M	08/25/86		E0.061
NG-91	3 -M	08/25/86		E0.078
NG-91	19 -M	08/25/86		E0.065
NG-91	42 -M	08/25/86		E0.044
NG-91	CRAB	08/25/86		E0.074
NG-92	61 -M	08/25/86	1	E0.040
NG-92	61 -M	08/25/86	2	E0.043
NG-92	61 -M	08/25/86	Mean	E0.042
NG-92	70 -M	08/25/86		E0.070
NG-92	81 -M	08/25/86		E0.034
NG-92	97 -M	08/25/86		E0.049
NG-92	111 -M	08/25/86		E0.061
NG-92	CRAB	NA	1	E0.085
NG-92	CRAB	NA	2	E0.093
NG-92	CRAB	NA	Mean	E0.089
NG-93	131 -M	08/26/86		E0.046
NG-93	133 -M	08/26/86		E0.013
NG-93	143 -M	08/26/86		E0.023
NG-93	161 -M	08/26/86		E0.063
NG-93	173 -M	08/26/86		E0.033
NG-93	CRAB	NA		E0.038
NG-94	666 -M	09/02/86		E0.060
NG-94	677 -M	09/02/86		E0.058
NG-94	687 -M	09/02/86		E0.041
NG-94	697 -M	09/02/86		E0.042
NG-94	717 -M	09/02/86		E0.037
NG-94	CRAB			E0.067

TABLE B-29. CONCENTRATIONS (UG/KG WET WEIGHT) OF PESTICIDES AND PCBS IN EVERETT HARBOR FISH AND CRAB TISSUE

Station	Sample	Sampling Date	Rep	p,p'-DDE	p,p'-DDD	p,p'-DDT	aldrin	dieldrin
EW-91	492 -M[a]	08/28/86		U0.4	U0.6	U0.7	U0.2	U0.3
EW-91	503 -M	08/28/86		U0.4	U0.6	U0.7	U0.2	U0.3
EW-91	514 -M	08/28/86		U0.4	U0.6	U0.7	U0.2	U0.3
EW-91	518 -M	08/29/86		U0.4	U0.6	U0.7	U0.2	U0.3
EW-91	527 -M	08/29/86		U0.4	U0.6	U0.7	U0.2	U0.3
EW-91	CRAB[b]	NA	1	U0.4	U0.6	U0.7	U0.2	U0.3
EW-91	CRAB	NA	2	U0.4	U0.6	U0.7	U0.2	U0.3
EW-91	CRAB	NA	Mean	U0.4	U0.6	U0.7	U0.2	U0.3
EW-91	CRAB2	NA		U0.4	U0.6	U0.7	U0.2	U0.3
EW-91	CRAB3	NA		U0.4	U0.6	U0.7	U0.2	U0.3
EW-92	311 -M	08/27/86	1	U0.4	U0.6	U0.7	U0.2	U0.3
EW-92	311 -M	08/27/86	2	U0.4	U0.6	U0.7	U0.2	U0.3
EW-92	311 -M	08/27/86	Mean	U0.4	U0.6	U0.7	U0.2	U0.3
EW-92	318 -M	08/27/86		U0.4	U0.6	U0.7	U0.2	U0.3
EW-92	325 -M	08/27/86		U0.4	U0.6	U0.7	U0.2	U0.3
EW-92	340 -M	08/27/86		U0.4	U0.6	U0.7	U0.2	U0.3
EW-92	350 -M	08/27/86		U0.4	U0.6	U0.7	U0.2	U0.3
EW-92	CRAB	NA	1	U0.4	U0.6	U0.7	U0.2	U0.3
EW-92	CRAB	NA	2	U0.4	U0.6	U0.7	U0.2	U0.3
EW-92	CRAB	NA	Mean	U0.4	U0.6	U0.7	U0.2	U0.3
NG-91	2 -M	08/25/86	1	U0.4	U0.6	U0.7	U0.2	U0.3
NG-91	2 -M	08/25/86	2	U0.4	U0.6	U0.7	U0.2	U0.3
NG-91	2 -M	08/25/86	Mean	U0.4	U0.6	U0.7	U0.2	U0.3
NG-91	3 -M	08/25/86		U0.4	U0.6	U0.7	U0.2	U0.3
NG-91	19 -M	08/25/86		U0.4	U0.6	U0.7	U0.2	U0.3
NG-91	42 -M	08/25/86		U0.4	U0.6	U0.7	U0.2	U0.3
NG-91	48 -M	08/25/86		U0.4	U0.6	U0.7	U0.2	U0.3
NG-91	CRAB	08/25/86	1	U0.4	U0.6	U0.7	U0.2	U0.3
NG-91	CRAB	08/25/86	2	U0.4	U0.6	U0.7	U0.2	U0.3
NG-91	CRAB	08/25/86	Mean	U0.4	U0.6	U0.7	U0.2	U0.3
NG-92	61 -M	08/25/86	1	U0.4	U0.6	U0.7	U0.2	U0.3
NG-92	61 -M	08/25/86	2	U0.4	U0.6	U0.7	U0.2	U0.3
NG-92	61 -M	08/25/86	Mean	U0.4	U0.6	U0.7	U0.2	U0.3
NG-92	70 -M	08/25/86		U0.4	U0.6	U0.7	U0.2	U0.3
NG-92	81 -M	08/25/86		U0.4	U0.6	U0.7	U0.2	U0.3
NG-92	97 -M	08/25/86		U0.4	U0.6	U0.7	U0.2	U0.3
NG-92	111 -M	08/25/86		U0.4	U0.6	U0.7	U0.2	U0.3
NG-92	CRAB	NA	1	U0.4	U0.6	U0.7	U0.2	U0.3
NG-92	CRAB	NA	2	U0.4	U0.6	U0.7	U0.2	U0.3
NG-92	CRAB	NA	Mean	U0.4	U0.6	U0.7	U0.2	U0.3
NG-93	131 -M	08/26/86		U0.4	U0.6	U0.7	U0.2	U0.3
NG-93	133 -M	08/26/86		U0.4	U0.6	U0.7	U0.2	U0.3
NG-93	143 -M	08/26/86		U0.4	U0.6	U0.7	U0.2	U0.3
NG-93	161 -M	08/26/86		U0.4	U0.6	U0.7	U0.2	U0.3
NG-93	173 -M	08/26/86		U0.4	U0.6	U0.7	U0.2	U0.3

TABLE B-29. (Continued)

Station	Sample	Sampling Date	Rep	alpha-HCH	beta-HCH	delta-HCH	gamma-HCH (lindane)	chlordane
EW-91	492 -M	08/28/86		U0.1	U0.4	U0.4	U0.2	U3.4
EW-91	503 -M	08/28/86		U0.1	U0.4	U0.4	U0.2	U3.4
EW-91	514 -M	08/28/86		U0.1	U0.4	U0.4	U0.2	U3.4
EW-91	518 -M	08/29/86		U0.1	U0.4	U0.4	U0.2	U3.4
EW-91	527 -M	08/29/86		U0.1	U0.4	U0.4	U0.2	U3.4
EW-91	CRAB	NA	1	U0.1	U0.4	U0.4	U0.2	U3.4
EW-91	CRAB	NA	2	U0.1	U0.4	U0.4	U0.2	U3.4
EW-91	CRAB	NA	Mean	U0.1	U0.4	U0.4	U0.2	U3.4
EW-91	CRAB2	NA		U0.1	U0.4	U0.4	U0.2	U3.4
EW-91	CRAB3	NA		U0.1	U0.4	U0.4	U0.2	U3.4
EW-92	311 -M	08/27/86	1	U0.1	U0.4	U0.4	U0.2	U3.4
EW-92	311 -M	08/27/86	2	U0.1	U0.4	U0.4	U0.2	U3.4
EW-92	311 -M	08/27/86	Mean	U0.1	U0.4	U0.4	U0.2	U3.4
EW-92	318 -M	08/27/86		U0.1	U0.4	U0.4	U0.2	U3.4
EW-92	325 -M	08/27/86		U0.1	U0.4	U0.4	U0.2	U3.4
EW-92	340 -M	08/27/86		U0.1	U0.4	U0.4	U0.2	U3.4
EW-92	350 -M	08/27/86		U0.1	U0.4	U0.4	U0.2	U3.4
EW-92	CRAB	NA	1	U0.1	U0.4	U0.4	U0.2	U3.4
EW-92	CRAB	NA	2	U0.1	U0.4	U0.4	U0.2	U3.4
EW-92	CRAB	NA	Mean	U0.1	U0.4	U0.4	U0.2	U3.4
NG-91	2 -M	08/25/86	1	U0.1	U0.4	U0.4	U0.2	U3.4
NG-91	2 -M	08/25/86	2	U0.1	U0.4	U0.4	U0.2	U3.4
NG-91	2 -M	08/25/86	Mean	U0.1	U0.4	U0.4	U0.2	U3.4
NG-91	3 -M	08/25/86		U0.1	U0.4	U0.4	U0.2	U3.4
NG-91	19 -M	08/25/86		U0.1	U0.4	U0.4	U0.2	U3.4
NG-91	42 -M	08/25/86		U0.1	U0.4	U0.4	U0.2	U3.4
NG-91	48 -M	08/25/86		U0.1	U0.4	U0.4	U0.2	U3.4
NG-91	CRAB	08/25/86	1	U0.1	U0.4	U0.4	U0.2	U3.4
NG-91	CRAB	08/25/86	2	U0.1	U0.4	U0.4	U0.2	U3.4
NG-91	CRAB	08/25/86	Mean	U0.1	U0.4	U0.4	U0.2	U3.4
NG-92	61 -M	08/25/86	1	U0.1	U0.4	U0.4	U0.2	U3.4
NG-92	61 -M	08/25/86	2	U0.1	U0.4	U0.4	U0.2	U3.4
NG-92	61 -M	08/25/86	Mean	U0.1	U0.4	U0.4	U0.2	U3.4
NG-92	70 -M	08/25/86		U0.1	U0.4	U0.4	U0.2	U3.4
NG-92	81 -M	08/25/86		U0.1	U0.4	U0.4	U0.2	U3.4
NG-92	97 -M	08/25/86		U0.1	U0.4	U0.4	U0.2	U3.4
NG-92	111 -M	08/25/86		U0.1	U0.4	U0.4	U0.2	U3.4
NG-92	CRAB	NA	1	U0.1	U0.4	U0.4	U0.2	U3.4
NG-92	CRAB	NA	2	U0.1	U0.4	U0.4	U0.2	U3.4
NG-92	CRAB	NA	Mean	U0.1	U0.4	U0.4	U0.2	U3.4
NG-93	131 -M	08/26/86		E0.2	U0.4	U0.4	U0.2	U3.4
NG-93	133 -M	08/26/86		U0.1	U0.4	U0.4	U0.2	U3.4
NG-93	143 -M	08/26/86		E0.3	U0.4	U0.4	U0.2	U3.4
NG-93	161 -M	08/26/86		U0.1	U0.4	U0.4	U0.2	U3.4
NG-93	173 -M	08/26/86		U0.1	U0.4	U0.4	U0.2	U3.4

TABLE B-29. (Continued)

Station	Sample	Sampling Date	Rep	endrin	endrin-aldehyde	hepta-chlor	total PCBs
EW-91	492 -M	08/28/86		U0.7	U0.8	U0.2	G42
EW-91	503 -M	08/28/86		U0.7	U0.8	U0.2	G25
EW-91	514 -M	08/28/86		U0.7	U0.8	U0.2	G16
EW-91	518 -M	08/29/86		U0.7	U0.8	U0.2	G13
EW-91	527 -M	08/29/86		U0.7	U0.8	U0.2	G18
EW-91	CRAB	NA	1	U0.7	U0.8	U0.2	EG5
EW-91	CRAB	NA	2	U0.7	U0.8	U0.2	EG9
EW-91	CRAB	NA	Mean	U0.7	U0.8	U0.2	EG7
EW-91	CRAB2	NA		U0.7	U0.8	U0.2	EG10
EW-91	CRAB3	NA		U0.7	U0.8	U0.2	G3
EW-92	311 -M	08/27/86	1	U0.7	U0.8	U0.2	G42
EW-92	311 -M	08/27/86	2	U0.7	U0.8	U0.2	G19
EW-92	311 -M	08/27/86	Mean	U0.7	U0.8	U0.2	G30
EW-92	318 -M	08/27/86		U0.7	U0.8	U0.2	G63
EW-92	325 -M	08/27/86		U0.7	U0.8	U0.2	G20
EW-92	340 -M	08/27/86		U0.7	U0.8	U0.2	G20
EW-92	350 -M	08/27/86		U0.7	U0.8	U0.2	G19
EW-92	CRAB	NA	1	U0.7	U0.8	U0.2	G11
EW-92	CRAB	NA	2	U0.7	U0.8	U0.2	G17
EW-92	CRAB	NA	Mean	U0.7	U0.8	U0.2	G14
NG-91	2 -M	08/25/86	1	U0.7	U0.8	U0.2	G100
NG-91	2 -M	08/25/86	2	U0.7	U0.8	U0.2	G28
NG-91	2 -M	08/25/86	Mean	U0.7	U0.8	U0.2	G64
NG-91	3 -M	08/25/86		U0.7	U0.8	U0.2	G30
NG-91	19 -M	08/25/86		U0.7	U0.8	U0.2	EG36
NG-91	42 -M	08/25/86		U0.7	U0.8	U0.2	EG25
NG-91	48 -M	08/25/86		U0.7	U0.8	U0.2	EG20
NG-91	CRAB	08/25/86	1	U0.7	U0.8	U0.2	G12
NG-91	CRAB	08/25/86	2	U0.7	U0.8	U0.2	G12
NG-91	CRAB	08/25/86	Mean	U0.7	U0.8	U0.2	G12
NG-92	61 -M	08/25/86	1	U0.7	U0.8	U0.2	EG72
NG-92	61 -M	08/25/86	2	U0.7	U0.8	U0.2	G21
NG-92	61 -M	08/25/86	Mean	U0.7	U0.8	U0.2	EG46
NG-92	70 -M	08/25/86		U0.7	U0.8	U0.2	EG91
NG-92	81 -M	08/25/86		U0.7	U0.8	U0.2	EG37
NG-92	97 -M	08/25/86		U0.7	U0.8	U0.2	EG27
NG-92	111 -M	08/25/86		U0.7	U0.8	U0.2	G12
NG-92	CRAB	NA	1	U0.7	U0.8	U0.2	G21
NG-92	CRAB	NA	2	U0.7	U0.8	U0.2	G26
NG-92	CRAB	NA	Mean	U0.7	U0.8	U0.2	G24
NG-93	131 -M	08/26/86		U0.7	U0.8	U0.2	G37
NG-93	133 -M	08/26/86		U0.7	U0.8	U0.2	G21
NG-93	143 -M	08/26/86		U0.7	U0.8	U0.2	G21
NG-93	161 -M	08/26/86		U0.7	U0.8	U0.2	EG10
NG-93	173 -M	08/26/86		U0.7	U0.8	U0.2	EG9
NG-93	CRAB	NA		U0.7	U0.8	U0.2	EG4

APPENDIX C

CORRELATION MATRICES FOR SELECTED CHEMICALS

LPAH correlations including all stations (detected data only)

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Correlations:  NAPHLN     ACENY      ACENE      FLUORENE   PHNTH      ANTHR

  NAPHLN                   .6916      .8118      .7435      .7250      .6366
                         (   39)    (   43)    (   23)    (   42)    (   44)
                         P= .000    P= .000    P= .000    P= .000    P= .000

  ACENY                               .8606      .8594      .8280      .7743
                                    (   39)    (   23)    (   40)    (   40)
                                    P= .000    P= .000    P= .000    P= .000

  ACENE                                          .9926      .8648      .9090
                                               (   24)    (   41)    (   44)
                                               P=0.0      P= .000    P= .000

  FLUORENE                                                  .8257      .9277
                                                          (   24)    (   24)
                                                          P= .000    P= .000

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed
-----------------------------------------------------------------------------

Correlations:  NAPHLN     ACENY      ACENE      FLUORENE   PHNTH      ANTHR

  PHNTH                                                                .6214
                                                                     (   47)
                                                                     P= .000




(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed
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APPENDIX D

SUMMARY OF AMPHIPOD BIOASSAY DATA

APPENDIX D. SUMMARY OF AMPHIPOD BIOASSAY DATA

Station	Date	Control Sample Number	Bioassay Run Number	Initial Number	Final Number	Percent Mortality
ES-01	10/06/86	CONTB	2	20	20	0.0
ES-01	10/06/86	CONTB	2	20	17	15.0
ES-01	10/06/86	CONTB	2	20	17	15.0
ES-01	10/06/86	CONTB	2	20	20	0.0
ES-01	10/06/86	CONTB	2	20	16	20.0
ES-02	10/06/86	CONTB	2	20	17	15.0
ES-02	10/06/86	CONTB	2	20	19	5.0
ES-02	10/06/86	CONTB	2	20	19	5.0
ES-02	10/06/86	CONTB	2	20	18	10.0
ES-02	10/06/86	CONTB	2	20	15	25.0
ES-03	10/06/86	CONTB	2	20	20	0.0
ES-03	10/06/86	CONTB	2	20	17	15.0
ES-03	10/06/86	CONTB	2	20	17	15.0
ES-03	10/06/86	CONTB	2	20	16	20.0
ES-03	10/06/86	CONTB	2	20	15	25.0
EW-01	10/07/86	CONTB	2	20	0	100.00
EW-01	10/07/86	CONTB	2	20	0	100.00
EW-01	10/07/86	CONTB	2	20	0	100.00
EW-01	10/07/86	CONTB	2	20	0	100.00
EW-01	10/07/86	CONTB	2	20	0	100.00
EW-04	09/30/86	CONTB	2	20	1	95.0
EW-04	09/30/86	CONTB	2	20	0	100.00
EW-04	09/30/86	CONTB	2	20	0	100.00
EW-04	09/30/86	CONTB	2	20	0	100.00
EW-04	09/30/86	CONTB	2	20	0	100.00
EW-07	09/30/86	CONTA	1	20	0	100.00
EW-07	09/30/86	CONTA	1	20	1	95.0
EW-07	09/30/86	CONTA	1	20	0	100.00
EW-07	09/30/86	CONTA	1	20	12	40.0
EW-07	09/30/86	CONTA	1	20	15	25.0
EW-07	09/30/86	CONTA	1	20	8	60.0
EW-07	09/30/86	CONTA	1	20	7	65.0
EW-07	09/30/86	CONTA	1	20	8	60.0
EW-07	09/30/86	CONTA	1	20	2	90.0
EW-07	09/30/86	CONTA	1	20	0	100.00
EW-10	10/01/86	CONTA	1	20	0	100.00
EW-10	10/01/86	CONTA	1	20	14	30.0
EW-10	10/01/86	CONTA	1	20	18	10.0
EW-10	10/01/86	CONTA	1	20	0	100.00
EW-10	10/01/86	CONTA	1	20	13	35.0
EW-12	10/01/86	CONTB	2	20	17	15.0
EW-12	10/01/86	CONTB	2	20	18	10.0
EW-12	10/01/86	CONTB	2	20	18	10.0
EW-12	10/01/86	CONTB	2	20	16	20.0
EW-12	10/01/86	CONTB	2	20	18	10.0

APPENDIX D. (CONTINUED)

Station	Date	Control Sample Number	Bioassay Run Number	Initial Number	Final Number	Percent Mortality
NG-06	10/08/86	CONTC	3	20	9	55.0
NG-06	10/08/86	CONTC	3	20	10	50.0
NG-06	10/08/86	CONTC	3	20	10	50.0
NG-06	10/08/86	CONTC	3	20	13	35.0
NG-06	10/08/86	CONTC	3	20	15	25.0
NG-10	10/03/86	CONTB	2	20	18	10.0
NG-10	10/03/86	CONTB	2	20	19	5.0
NG-10	10/03/86	CONTB	2	20	20	0.0
NG-10	10/03/86	CONTB	2	20	19	5.0
NG-10	10/03/86	CONTB	2	20	19	5.0
NG-12	10/15/86	CONTD	4	20	20	0.0
NG-12	10/15/86	CONTD	4	20	20	0.0
NG-12	10/15/86	CONTD	4	20	20	0.0
NG-12	10/15/86	CONTD	4	20	20	0.0
NG-12	10/15/86	CONTD	4	20	18	10.0
NG-13	10/15/86	CONTD	4	20	20	0.0
NG-13	10/15/86	CONTD	4	20	19	5.0
NG-13	10/15/86	CONTD	4	20	18	10.0
NG-13	10/15/86	CONTD	4	20	18	10.0
NG-13	10/15/86	CONTD	4	20	19	5.0
NG-14	10/15/86	CONTD	4	20	18	10.0
NG-14	10/15/86	CONTD	4	20	20	0.0
NG-14	10/15/86	CONTD	4	20	20	0.0
NG-14	10/15/86	CONTD	4	20	18	10.0
NG-14	10/15/86	CONTD	4	20	19	5.0
NG-15	10/15/86	CONTD	4	20	19	5.0
NG-15	10/15/86	CONTD	4	20	20	0.0
NG-15	10/15/86	CONTD	4	20	20	0.0
NG-15	10/15/86	CONTD	4	20	20	0.0
NG-15	10/15/86	CONTD	4	20	20	0.0
OG-03	10/09/86	CONTC	3	20	2	90.0
OG-03	10/09/86	CONTC	3	20	7	65.0
OG-03	10/09/86	CONTC	3	20	10	50.0
OG-03	10/09/86	CONTC	3	20	17	15.0
OG-03	10/09/86	CONTC	3	20	6	70.0
PS-02	10/13/86	CONTC	3	20	12	40.0
PS-02	10/13/86	CONTC	3	20	16	20.0
PS-02	10/13/86	CONTC	3	20	13	35.0
PS-02	10/13/86	CONTC	3	20	14	30.0
PS-02	10/13/86	CONTC	3	20	16	20.0
PS-03	10/13/86	CONTC	3	20	15	25.0
PS-03	10/13/86	CONTC	3	20	12	40.0
PS-03	10/13/86	CONTC	3	20	17	15.0
PS-03	10/13/86	CONTC	3	20	17	15.0
PS-03	10/13/86	CONTC	3	20	15	25.0

APPENDIX D. (CONTINUED)

Station	Date	Control Sample Number	Bioassay Run Number	Initial Number	Final Number	Percent Mortality
SS-03	10/06/86	CONTA	1	20	16	20.0
SS-03	10/06/86	CONTA	1	20	18	10.0
SS-03	10/06/86	CONTA	1	20	17	15.0
SS-03	10/06/86	CONTA	1	20	17	15.0
SS-03	10/06/86	CONTA	1	20	17	15.0
SS-03	10/06/86	CONTB	2	20	18	10.0
SS-03	10/06/86	CONTB	2	20	20	0.0
SS-03	10/06/86	CONTB	2	20	18	10.0
SS-03	10/06/86	CONTB	2	20	20	0.0
SS-03	10/06/86	CONTB	2	20	18	10.0

APPENDIX E

SUMMARY OF BENTHIC STATION SEDIMENT GRAIN SIZE AND CONVENTIONAL DATA

TABLES

Number		Page
E-1	Sediment grain size characteristics at benthic stations in Port Susan and Everett Harbor	E-1
E-2	Conventional sediment characteristics at benthic stations in Port Susan and Everett Harbor	E-2

TABLE E-1. SEDIMENT GRAIN SIZE CHARACTERISTICS AT BENTHIC STATIONS IN PORT SUSAN AND EVERETT HARBOR

	Percent Grain Size							
Station	Gravel	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt	Clay
PS-02	0.1	0.3	3.7	36.6	36.3	11.5	2.3	9.2
PS-03	0.1	1.9	9.8	36.3	35.9	8.0	1.2	6.8
PS-04	1.2	11.5	16.8	23.2	32.9	7.1	0.7	6.7
NG-01	0.1	0.7	7.4	34.6	44.4	8.4	0.8	3.6
NG-02	1.8	7.4	35.3	40.8	9.6	2.1	0.3	2.8
NG-03	0.0	4.3	25.9	49.4	15.8	1.8	0.0	2.7
NG-04	0.1	3.0	19.9	38.3	31.3	3.7	0.7	2.9
NG-06	0.5	1.2	8.0	30.0	35.9	17.3	1.4	5.7
NG-10	11.8	6.1	20.9	26.8	25.3	4.9	1.0	3.2
EW-01	0.1	0.1	0.5	2.5	6.4	11.5	33.2	45.5
EW-04	18.0	3.2	6.0	3.0	3.6	7.3	4.2	54.7
EW-07	2.7	2.0	5.0	10.0	7.4	16.1	24.6	32.1
EW-10	3.4	0.3	1.4	3.6	4.6	9.6	36.7	40.4
EW-12	0.6	0.5	4.0	47.6	34.9	4.2	2.2	5.9
EW-14	38.0	4.2	9.3	5.2	4.4	6.6	19.6	12.6
SD-01	12.3	7.2	17.9	41.6	15.2	1.2	0.4	4.2
SD-02	0.0	0.1	2.1	14.4	55.8	16.1	5.7	5.8
SR-07	0.2	0.0	0.1	0.5	0.6	3.2	58.8	36.6
SR-08	5.3	0.6	2.9	28.1	25.0	16.0	13.2	8.9

APPENDIX F

ABUNDANCES OF MAJOR TAXA OF BENTHIC INFAUNA, AND BENTHIC INFAUNA DATA BY STATION AND REPLICATE

FIGURES

Number		Page
F-1	Mean abundance/m^2 of total benthic infauna at each benthic station in Everett Harbor and Port Susan	F-4
F-2	Mean abundance/m^2 of polychaetes at each benthic station in Everett Harbor and Port Susan	F-5
F-3	Mean abundance/m^2 of pelecypods at each benthic station in Everett Harbor and Port Susan	F-6
F-4	Mean abundance/m^2 of gastropods at each benthic station in Everett Harbor and Port Susan	F-7
F-5	Mean abundance/m^2 of total crustaceans at each benthic station in Everett Harbor and Port Susan	F-8
F-6	Mean abundance/m^2 of crustaceans excluding amphipods at each benthic station in Everett Harbor and Port Susan	F-9
F-7	Mean abundance/m^2 of amphipods at each benthic station in Everett Harbor and Port Susan	F-10
F-8	Mean abundance/m^2 of echinoderms at each benthic station in Everett Harbor and Port Susan	F-11
F-9	Mean abundance/m^2 of miscellaneous taxa at each benthic station in Everett Harbor and Port Susan	F-12

TABLES

Number		Page
F-1	Abundances of major taxa of benthic infauna	F-1
F-2	Benthic infauna data by station and replicate	F-13

TABLE F-1. ABUNDANCES OF MAJOR TAXA OF BENTHIC INFAUNA

Station	Rep	Polychaetes	Pelecypods	Gastropods	Total Crustaceans	Amphipods	Other Crustaceans	Echinoderms	Misc Taxa	Total
EW-01	V1	35	0	0	3	0	3	0	46	84
EW-01	V2	31	0	0	25	0	25	0	87	143
EW-01	V3	25	0	0	1	0	1	0	14	40
EW-01	V4	106	0	0	1	0	1	0	47	154
EW-01	V5	41	1	1	1	0	1	0	116	160
EW-04	V1	1202	2	0	37	14	23	0	142	1383
EW-04	V2	1967	6	2	432	74	358	0	848	3255
EW-04	V3	1530	4	0	162	19	143	0	855	2551
EW-04	V4	909	2	1	23	7	16	0	291	1226
EW-04	V5	1623	1	1	128	17	111	0	170	1923
EW-07	V1	19	5	0	7	7	0	0	16	47
EW-07	V2	27	1	0	62	26	36	0	6	96
EW-07	V3	18	6	1	42	14	28	0	16	83
EW-07	V4	20	9	0	8	2	6	0	24	61
EW-07	V5	26	6	1	10	6	4	0	37	80
EW-10	V1	1453	17	6	381	34	347	0	31	1888
EW-10	V2	959	18	38	672	142	530	0	24	1711
EW-10	V3	442	7	2	132	65	67	0	395	978
EW-10	V4	467	31	13	123	53	70	0	192	826
EW-10	V5	793	25	35	417	152	265	0	116	1386
EW-12	V1	135	99	107	1526	444	1082	0	8	1875
EW-12	V2	73	49	8	623	272	351	0	5	758
EW-12	V3	83	78	160	1359	310	1049	1	13	1694
EW-12	V4	80	67	20	1229	280	949	1	2	1399
EW-12	V5	67	74	38	585	255	330	0	0	764
EW-14	V1	178	51	71	297	161	136	1	195	793
EW-14	V2	52	29	29	71	20	51	0	1	182
EW-14	V3	231	53	32	296	133	163	0	125	737
EW-14	V4	235	37	18	420	244	176	0	44	754
EW-14	V5	93	26	2	166	108	58	0	22	309
NG-01	V1	90	148	7	227	5	222	0	3	475
NG-01	V2	64	145	10	137	5	132	0	0	356
NG-01	V3	209	214	14	263	7	256	0	6	706
NG-01	V4	78	120	8	219	7	212	0	1	426
NG-01	V5	55	190	7	114	6	108	0	2	368
NG-02	V1	49	39	5	129	1	128	0	6	228
NG-02	V2	70	71	3	130	4	126	0	10	284
NG-02	V3	51	81	1	170	2	168	0	3	306
NG-02	V4	58	94	3	130	4	126	0	7	292
NG-02	V5	49	52	2	123	1	122	0	3	229
NG-03	V1	17	565	39	206	5	201	0	1	828
NG-03	V2	87	651	54	284	25	259	0	11	1087
NG-03	V3	72	411	26	283	32	251	0	6	798
NG-03	V4	77	522	37	253	21	232	0	6	895
NG-03	V5	57	582	39	291	26	265	0	0	969
NG-04	V1	37	275	102	201	16	185	0	0	615

TABLE F-1. (CONTINUED)

Station	Rep	Polychaetes	Pelecypods	Gastropods	Total Crustaceans	Amphipods	Other Crustaceans	Echinoderms	Misc Taxa	Total
SR-08	V3	127	88	7	278	93	185	0	31	531
SR-08	V4	96	46	9	222	132	90	0	12	385
SR-08	V5	128	38	5	210	94	116	0	41	422

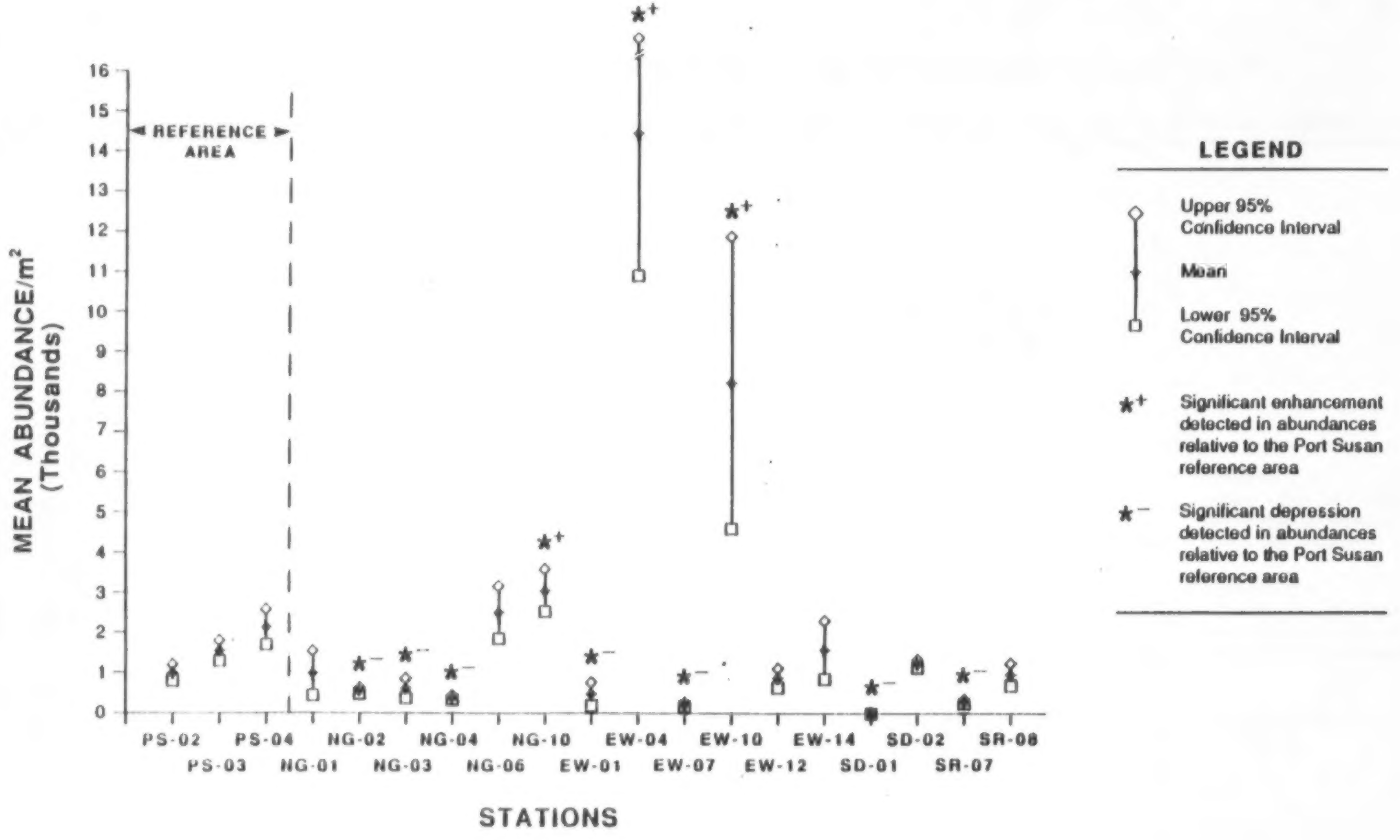

Figure F-2. Mean abundance/m^2 of polychaetes at each benthic station in Everett Harbor and Port Susan.

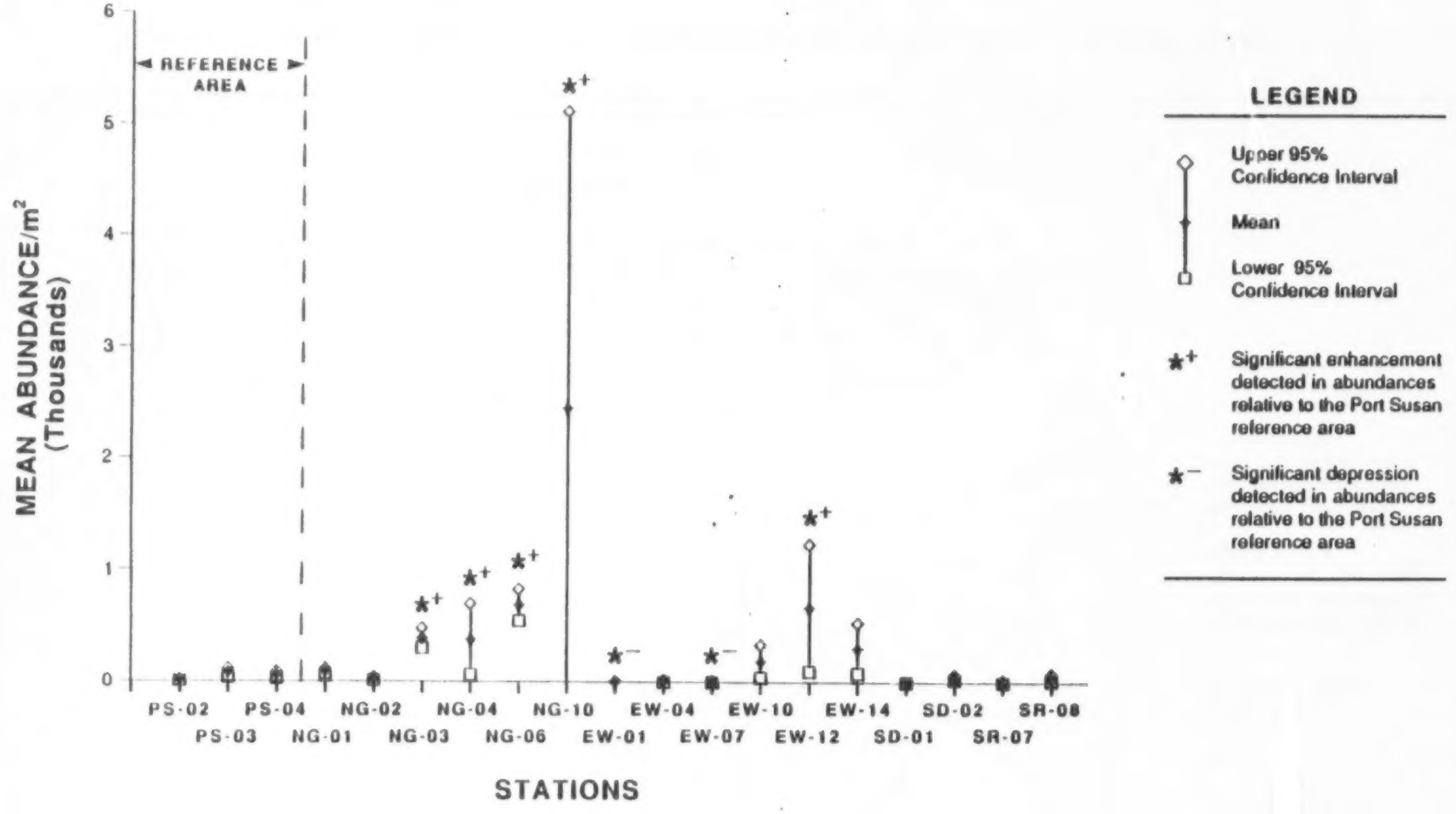

Figure F-4. Mean abundance/m^2 of gastropods at each benthic station in Everett Harbo
and Port Susan.

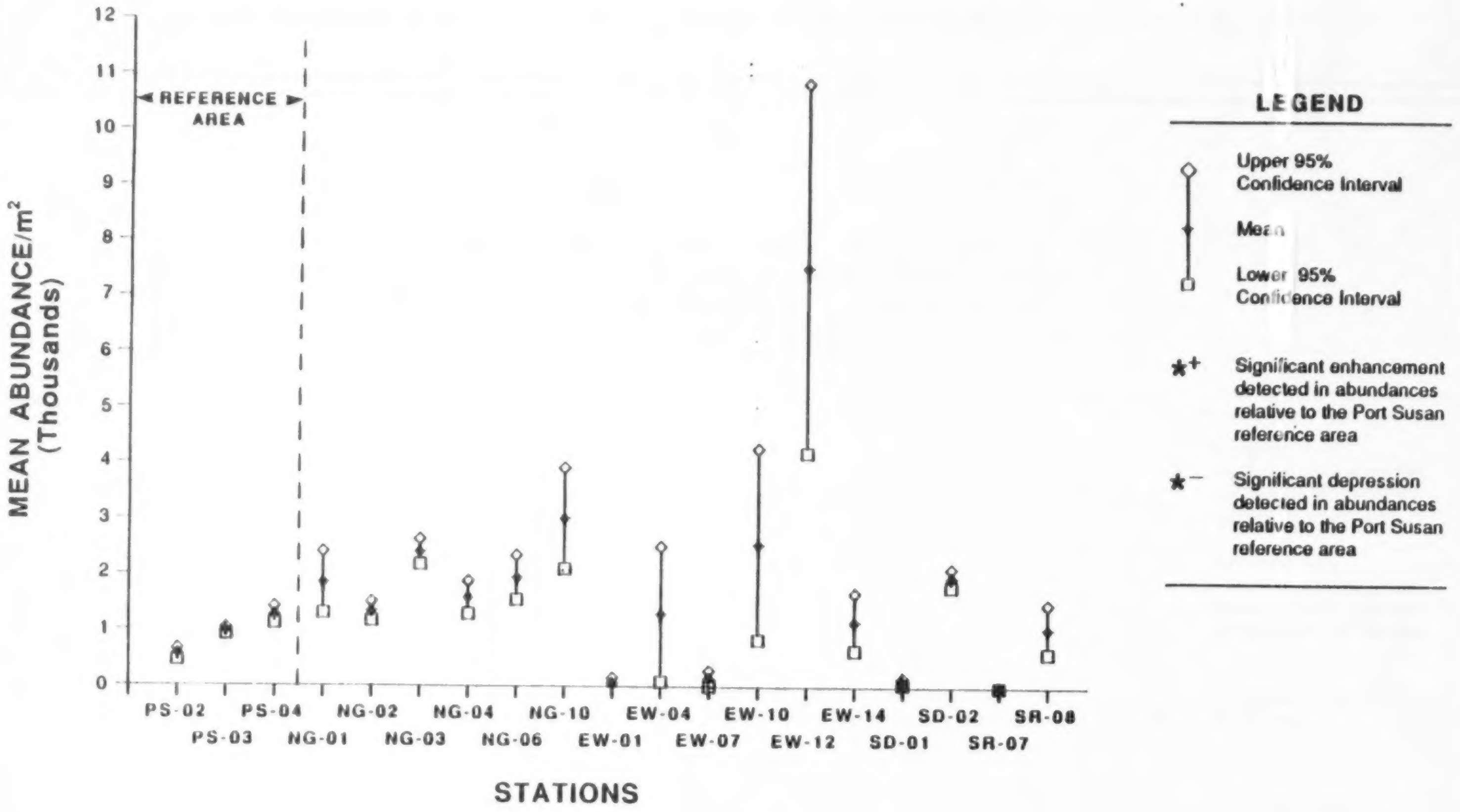

Figure F-6. Mean abundance/m^2 of crustaceans excluding amphipods at each benthic station in Everett Harbor and Port Susan.

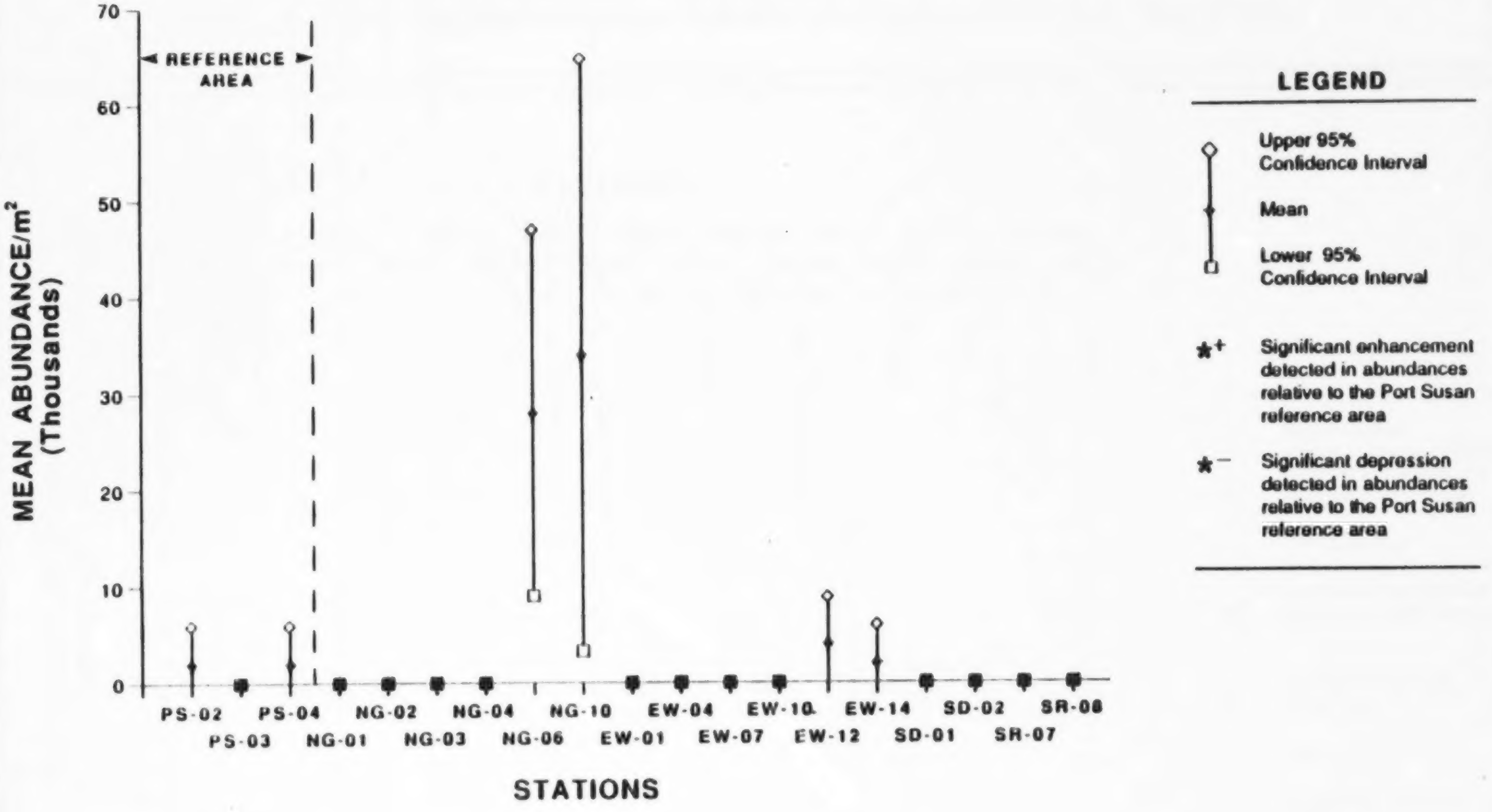

Figure F-8. Mean abundance/m^2 of echinoderms at each benthic station in Everett Harbor and Port Susan.

TABLE F-2. BENTHIC INFAUNA DATA BY STATION AND REPLICATE

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total	
EW-01	47	Nematoda	46	87	14	47	116	310	
	5001240501	Platynereis bicanaliculata	0	6	0	0	1	7	
	5001600101	Capitella capitata	35	25	25	106	40	231	
	5110070101	Gastropteron pacificum	0	0	0	0	1	1	
	55153101	Macoma spp.	0	0	0	0	1	1	
	6134020104	Balanus crenatus	0	2	0	0	0	2	
	61450101	Nebalia spp.	2	23	0	0	0	25	
	61570201	Leptochelia spp.	1	0	0	0	0	1	
	6161020301	Gnorimosphaeroma oregonensis	0	0	0	1	0	1	
	6161050102	Limnoria algarum	0	0	1	0	1	2	
			84	143	40	154	160	581	Sum
			8	14	4	15	16	58	Ave
			293	746	74	1230	1389	12932	Var
			0	0	0	0	0	1	Min
			46	87	25	106	116	310	Max

Number of Observations: 10

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total	
EW-07	47	Nematoda	15	5	15	23	37	95	
	50011302	Eteone spp.	1	0	0	0	1	2	
	5001130205	Eteone longa	0	0	0	1	1	2	
	5001210102	Gyptis brevipalpa	0	0	0	1	0	1	
	5001210801	Micropodarke dubia	1	0	0	0	0	1	
	5001240301	Nereis brandti	0	1	0	1	0	2	
	5001240404	Nereis procera	0	1	0	1	0	2	
	5001240501	Platynereis bicanaliculata	0	10	2	0	0	12	
	5001250103	Nephtys caeca	0	0	1	0	0	1	
	50014305	Prionospio spp.	0	0	1	0	0	1	
	5001430599	Prionospio multibranchiata	0	0	0	2	0	2	
	5001580202	Armandia brevis	0	2	3	6	1	12	
	5001600101	Capitella capitata	17	13	10	8	23	71	
	50016807	Pista spp.	0	0	1	0	0	1	
	5004	Oligochaeta	1	1	1	1	0	4	
	51032001	Alvania spp.	0	0	1	0	1	2	
	5515310102	Macoma elimata	1	0	3	0	3	7	
	5515310112	Macoma carlottensis	1	0	0	1	0	2	
	5515310114	Macoma nasuta	3	1	3	6	3	16	
	5517010101	Cryptomya californica	0	0	0	2	0	2	
	6111070301	Euphilomedes carcharodonta	0	1	0	0	0	1	
	61340201	Balanus spp.	0	6	3	0	0	9	
	6134020104	Balanus crenatus	0	15	17	0	2	34	
	61450101	Nebalia spp.	0	4	8	1	1	14	
	6154050101	Diastylis alaskensis	0	0	0	2	1	3	
	6157020103	Leptochelia dubia	0	1	0	0	0	1	
	61690602	Aoroides spp	2	4	4	2	0	12	
	6169060204	Aoroides spinosus	5	18	8	0	4	35	
	6169210106	Anisogammarus pugettensis	0	1	0	0	0	1	
	6169211003	Melita dentata	0	1	0	0	0	1	
	6169211008	Melita desdichada	0	1	0	0	0	1	
	61692602	Photis spp.	0	1	2	0	2	5	
	617916	Hippolytidae	0	3	0	0	0	3	
	61791605	Heptacarpus spp.	0	4	0	0	0	4	
	61792201	Crangon spp.	0	0	0	1	0	1	
	61880301	Cancer spp.	0	2	0	0	0	2	
	6188030105	Cancer gracilis	0	0	0	1	0	1	
	61890604	Pinnixa spp.	0	0	0	1	0	1	
			47	96	83	61	80	367	Sum
			1	3	2	2	2	10	Ave
			13	19	17	16	48	379	Var
			0	0	0	0	0	1	Min
			17	18	17	23	37	95	Max

Number of Observations: 38

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total	
EW-10	6169210106	Anisogammarus pugettensis	0	0	1	0	0	1	
	61692110	Melita spp.	1	0	0	0	4	5	
	6169211003	Melita dentata	2	2	1	0	11	16	
	6169211005	Melita californica	5	38	5	1	32	81	
	6169211008	Melita desdichada	2	11	1	3	17	34	
	6169240204	Hyale plumulosa	0	0	1	0	0	1	
	61692602	Photis spp.	0	0	3	0	0	3	
	6169260201	Photis brevipes	0	0	0	7	1	8	
	6169371402	Synchelidium shoemakeri	0	0	0	1	0	1	
	6169420602	Metaphoxus fultoni	0	1	0	0	0	1	
	6169421504	Rhepoxynius abronius	0	1	0	0	0	1	
	617916	Hippolytidae	0	5	1	2	3	11	
	6179160408	Eualus pusiolus	0	4	0	1	0	5	
	61791605	Heptacarpus spp.	0	0	0	0	1	1	
	6179160511	Heptocarpus stimpsoni	0	0	0	0	1	1	
	6179180107	Pandalus danae	0	1	0	0	0	1	
	61880301	Cancer spp.	0	2	0	0	0	2	
	6188030105	Cancer gracilis	2	0	0	2	0	4	
	618902010102	Lophopanopeus bellus diegensis	0	0	0	0	2	2	
	618906	Pinnotheridae	1	0	0	0	0	1	
			1888	1711	978	826	1386	6789	Sum
			27	24	14	12	20	97	Ave
			****	****	4588	3306	8165	*****	Var
			0	0	0	0	0	1	Min
			1347	855	412	443	716	3773	Max

Number of Observations: 70

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
EW-12	5515100102	Mysella tumida	11	10	14	22	9	66
	55152201	Clinocardium spp.	0	0	0	0	17	17
	5515220102	Clinocardium nuttali	4	4	7	7	0	22
	5515310106	Macoma obliqua	36	0	17	7	15	75
	5515310114	Macoma nasuta	25	17	7	12	15	76
	5515310116	Macoma balthica	0	8	0	0	0	8
	5515310204	Tellina modesta	0	0	1	1	1	3
	5515470201	Saxidomus giganteus	5	1	13	4	1	24
	5515470701	Protothaca staminea	4	1	3	2	0	10
	5517010201	Mya arenaria	1	4	3	2	2	12
	5518020101	Bankia setacea	0	0	0	0	1	1
	6111070301	Euphilomedes carcharodonta	25	5	24	17	0	71
	6111070303	Euphilomedes producta	0	0	0	0	26	26
	61340201	Balanus spp.	0	0	7	3	0	10
	6134020104	Balanus crenatus	23	32	0	3	1	59
	61450101	Nebalia spp.	8	0	0	1	0	9
	6151	Mysidacea	0	0	1	0	0	1
	6154050101	Diastylis alaskensis	2	0	1	0	0	3
	6154080102	Cumella vulgaris	6	1	4	0	1	12
	61570201	Leptochelia spp.	148	21	87	89	19	364
	6157020103	Leptochelia dubia	847	282	918	827	257	3131
	6161020301	Gnorimosphaeroma oregonensis	3	0	1	0	1	5
	6161050102	Limnoria algarum	3	6	0	0	8	17
	616312	Munnidae	4	0	0	0	0	4
	61690602	Aoroides spp	0	2	0	0	0	2
	6169090105	Atylus collingi	0	0	0	1	0	1
	61691502	Corophium spp.	25	24	32	32	25	138
	6169150201	Corophium acherusicum	40	41	22	34	33	170
	6169150999	Grandidierella japonica	0	0	2	0	0	2
	6169210106	Anisogammarus pugettensis	0	33	1	4	1	39
	61692110	Melita spp.	7	0	0	0	0	7
	6169211003	Melita dentata	0	2	0	0	0	2
	6169211005	Melita californica	14	7	0	2	0	23
	6169211008	Melita desdichada	32	3	3	3	0	41
	61692602	Photis spp.	62	15	35	36	98	246
	6169260201	Photis brevipes	168	124	153	136	68	649
	616934	Lysianassidae	3	0	3	2	0	8
	6169342904	Orchomene pinquis	28	11	38	17	27	121
	6169371402	Synchelidium shoemakeri	3	0	0	0	0	3
	616942	Phoxocephalidae	2	0	0	0	1	3
	6169420928	Eobrolgus spinosus	60	9	21	13	2	105
	61694303	Parapleustes spp.	0	1	0	0	0	1
	61830402	Callianassa spp.	8	4	4	4	14	34
	61880301	Cancer spp.	3	0	0	2	0	5
	6188030105	Cancer gracilis	1	0	2	2	3	8
	61890604	Pinnixa spp.	1	0	0	1	0	2
	72000201	Golfingia spp.	0	0	1	0	0	1
	8104	Asteroidea	0	0	0	1	0	1
	8129030104	Amphiodia urtica	0	0	1	0	0	1

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
EW-14	39	Platyhelminthes	0	0	1	0	0	1
	3906	Polycladida	0	0	0	2	0	2
	43020101	Tubulanus spp.	20	0	0	0	0	20
	430302	Lineidae	0	0	6	0	0	6
	43030202	Cerebratulus spp.	1	0	1	0	0	2
	43030205	Micrura spp.	3	0	8	2	0	13
	43060501	Amphiporus spp.	0	0	0	1	0	1
	43060503	Zygonemertes spp.	1	0	0	0	0	1
	430606029999	Tetrastemma sp. A (Everett Harbor only)	1	0	0	0	0	1
	47	Nematoda	168	1	108	38	20	335
	5001020603	Gattyana cirrosa	0	0	2	0	0	2
	5001020806	Harmothoe imbricata	1	0	3	2	0	6
	5001020810	Harmothoe lunulata	2	0	0	2	0	4
	50010217	Hesperonoe spp.	0	1	0	0	0	1
	5001060101	Pholoe minuta	3	0	3	1	0	7
	5001130102	Phyllodoce (Anaitides) groenlandica	1	0	2	1	1	5
	5001130114	Phyllodoce (Anaitides) williamsi	1	0	0	0	0	1
	5001130301	Eulalia viridis	0	0	3	0	0	3
	5001130303	Eulalia aviculiseta	1	0	0	0	0	1
	5001131402	Phyllodoce (Aponaitides) hartmanae	0	0	0	1	0	1
	5001131411	Phyllodoce (Anaitides) cuspidata	3	0	0	0	0	3
	5001210102	Gyptis brevipalpa	0	1	1	4	0	6
	5001210801	Micropodarke dubia	0	0	2	1	0	3
	500121159999	Podarke sp. A (Everett Harbor only)	0	0	0	1	0	1
	5001230703	Exogone lourei	0	0	1	0	0	1
	5001240201	Cheilonereis spp.	0	0	1	0	0	1
	50012404	Nereis spp.	2	0	0	0	1	3
	5001240404	Nereis procera	1	0	0	1	0	2
	5001240501	Platynereis bicanaliculata	45	6	30	32	23	136
	5001250102	Nephtys ciliata	0	0	0	2	0	2
	5001270101	Glycera capitata	2	0	2	1	1	6
	5001270104	Glycera americana	0	0	0	1	0	1
	5001280101	Glycinde picta	0	3	3	5	1	12
	5001280103	Glycinde armigera	2	0	0	0	0	2
	5001290202	Diopatra ornata	0	0	1	0	0	1
	50013101	Lumbrineris spp.	0	0	0	2	0	2
	5001310109	Lumbrineris luti	0	0	5	2	0	7
	5001310118	Lumbrineris cruzensis	0	0	2	0	0	2
	5001310194	Lumbrineris sp. gr. 4	0	0	21	5	0	26
	5001310195	Lumbrineris sp. gr. 3	8	2	0	0	4	14
	5001310197	Lumbrineris sp. gr. 1	1	1	8	4	1	15
	5001360504	Schistomeringos rudolphi	3	0	2	3	1	9
	5001360507	Schistomeringos japonica	1	0	0	0	0	1
	5001400102	Leitoscoloplos pugettensis	0	0	1	0	0	1
	50014305	Prionospio spp.	9	1	2	0	5	17
	5001430502	Prionospio cirrifera	36	12	65	107	14	234
	5001430506	Prionospio steenstrupi	9	1	14	25	9	58
	5001430599	Prionospio multibranchiata	1	3	1	3	5	13
	5001431004	Spiophanes berkelyorum	0	0	0	2	0	2
	5001490302	Spiochaetopterus costarum	1	0	0	0	1	2

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total	
EW-14	6157020103	Leptochelia dubia	1	0	0	1	0	2	
	6161050102	Limnoria algarum	1	0	0	0	0	1	
	6169	Gammaridea	0	0	1	0	0	1	
	616904	Ampithoidae	1	0	0	0	0	1	
	61690602	Aoroides spp	31	3	34	25	22	115	
	6169060204	Aoroides spinosus	85	7	62	86	69	309	
	6169060205	Aoroides exilis	9	0	12	13	10	44	
	61691502	Corophium spp.	0	0	0	2	0	2	
	6169150201	Corophium acherusicum	0	1	0	0	0	1	
	6169150999	Grandidierella japonica	0	0	0	0	1	1	
	61692110	Melita spp.	2	0	0	12	0	14	
	6169211003	Melita dentata	12	4	6	75	1	98	
	6169211005	Melita californica	6	0	3	9	0	18	
	6169211008	Melita desdichada	7	4	11	20	2	44	
	6169211901	Eogammarus oclairi	0	0	0	0	1	1	
	61692602	Photis spp.	5	1	1	1	2	10	
	6169342914	Orchomene decipiens	2	0	3	1	0	6	
	6169420602	Metaphoxus fultoni	1	0	0	0	0	1	
	617916	Hippolytidae	2	0	0	1	0	3	
	6179160408	Eualus pusiolus	0	2	0	3	1	6	
	61791605	Heptacarpus spp.	0	1	0	0	0	1	
	6179160510	Heptacarpus brevirostris	1	0	0	2	0	3	
	6179160511	Heptocarpus stimpsoni	0	0	0	2	0	2	
	61880301	Cancer spp.	0	0	0	1	0	1	
	6188030101	Cancer productus	2	0	1	3	3	9	
	6188030105	Cancer gracilis	0	1	0	0	0	1	
	6188030106	Cancer oregonensis	20	3	32	29	16	100	
	618902010102	Lophopanopeus bellus diegensis	3	5	0	5	2	15	
	61890604	Pinnixa spp.	14	5	14	13	3	49	
	6189060403	Pinnixa occidentalis	0	0	1	0	0	1	
	8149030201	Strongylocentrotus droebachiensis	1	0	0	0	0	1	
	84060105	Styela spp.	1	0	0	0	0	1	
			793	183	737	754	310	2777	Sum
			6	1	6	6	2	21	Ave
			384	14	257	304	55	3190	Var
			0	0	0	0	0	1	Min
			168	28	108	115	69	335	Max

Number of Observations: 132

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
NG-01	50016004	Mediomastus spp.	0	0	1	0	0	1
	5001600601	Barantolla americana	0	0	2	0	0	2
	50016309	Praxillella spp.	0	0	0	2	0	2
	5001631	Euclymeninae	1	1	23	1	2	28
	5001660303	Pectinaria granulata	12	11	9	4	4	40
	5001660304	Pectinaria californiensis	1	0	1	0	0	2
	50016702	Ampharete spp.	0	0	1	0	0	1
	5001670401	Lysippe labiata	0	0	2	0	0	2
	5001670801	Asabellides sibirica	1	0	0	0	0	1
	500168	Terebellidae	1	0	0	0	0	1
	50016807	Pista spp.	0	0	3	0	1	4
	5001680701	Pista cristata	0	0	0	2	0	2
	50016808	Polycirrus spp.	0	0	3	1	0	4
	50016810	Thelepus spp.	7	0	7	0	0	14
	5001681002	Thelepus hamatus	0	0	4	0	0	4
	500168130201	Lanassa venusta venusta	0	0	9	5	3	17
	50017001	Chone spp.	0	0	1	0	0	1
	51032001	Alvania spp.	0	1	1	1	0	3
	5103760201	Natica clausa	0	3	3	1	0	7
	5105030204	Mitrella gouldi	5	6	8	4	5	28
	51080102	Turbonilla spp.	2	0	0	2	2	6
	5110	Cephalaspidea	0	0	1	0	0	1
	5110070101	Gastropteron pacificum	0	0	1	0	0	1
	5502020201	Nucula tenuis	4	4	3	4	7	22
	5502040203	Nuculana fossa	0	0	0	1	0	1
	5515010101	Parvilucina tenuisculpta	0	0	0	1	0	1
	5515020201	Axinopsida serricata	89	39	172	68	77	445
	5515100102	Mysella tumida	4	1	4	2	7	18
	55152201	Clinocardium spp.	0	0	0	1	0	1
	5515220102	Clinocardium nuttali	1	4	0	0	0	5
	5515250104	Spisula falcata	0	2	0	0	0	2
	5515310102	Macoma elimata	0	0	2	0	0	2
	5515310106	Macoma obliqua	0	2	7	0	0	9
	5515310112	Macoma carlottensis	1	0	0	0	0	1
	5515310114	Macoma nasuta	8	5	5	8	5	31
	5515310116	Macoma balthica	1	0	0	0	0	1
	5515310204	Tellina modesta	2	4	2	1	2	11
	5515470501	Psephidia lordi	38	84	19	33	91	265
	5517010201	Mya arenaria	0	0	0	0	1	1
	5520020103	Pandora bilirata	0	0	0	1	0	1
	611103	Cylindroleberididae	0	1	0	1	0	2
	6111070301	Euphilomedes carcharodonta	208	128	208	200	108	852
	6111070303	Euphilomedes producta	11	0	26	8	0	45
	61450101	Nebalia spp.	0	1	2	1	0	4
	6154050101	Diastylis alaskensis	0	1	0	0	0	1
	6157020103	Leptochelia dubia	1	1	18	2	0	22
	6169020208	Byblis millsi	0	0	1	1	0	2
	61690602	Aoroides spp	0	0	0	2	0	2
	6169060204	Aoroides spinosus	0	0	0	1	0	1
	61692602	Photis spp.	0	0	1	0	0	1

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
NG-02	43020101	Tubulanus spp.	1	1	0	3	0	5
	4302010104	Tubulanus pellucidus	0	1	2	0	2	5
	43030202	Cerebratulus spp.	0	0	1	0	0	1
	43030205	Micrura spp.	4	6	0	4	1	15
	43060501	Amphiporus spp.	1	1	0	0	0	2
	43060602	Tetrastemma spp.	0	1	0	0	0	1
	50011302	Eteone spp.	0	0	0	0	1	1
	5001130205	Eteone longa	0	1	0	1	0	2
	5001131402	Phyllodoce (Aponaitides) hartmanae	0	1	0	1	0	2
	50012404	Nereis spp.	1	0	0	0	0	1
	5001250102	Nephtys ciliata	0	1	1	0	0	2
	5001250103	Nephtys caeca	0	2	1	1	0	4
	5001270104	Glycera americana	1	0	0	0	0	1
	5001280101	Glycinde picta	2	1	4	0	1	8
	5001280103	Glycinde armigera	0	0	1	1	3	5
	50012901	Onuphis spp.	0	0	1	1	0	2
	5001290111	Onuphis elegans	0	0	0	1	1	2
	5001310109	Lumbrineris luti	1	0	0	0	1	2
	5001310197	Lumbrineris sp. gr. 1	1	0	0	0	0	1
	5001400102	Leitoscoloplos pugettensis	4	5	4	0	0	13
	5001400301	Scoloplos armiger	27	36	23	30	23	139
	5001400311	Scoloplos acmeceps	1	0	0	1	0	2
	5001410201	Aricidea suecica	0	2	1	0	1	4
	50014305	Prionospio spp.	0	0	0	0	1	1
	5001430506	Prionospio steenstrupi	2	9	4	6	10	31
	5001430599	Prionospio multibranchiata	1	0	0	0	0	1
	5001431001	Spiophanes bombyx	0	0	0	2	0	2
	5001490302	Spiochaetopterus costarum	0	1	1	0	1	3
	50015003	Tharyx spp.	0	1	0	0	0	1
	50015004	Chaetozone spp.	1	0	5	3	2	11
	5001580202	Armandia brevis	2	0	0	0	0	2
	50016003	Notomastus spp.	0	0	0	0	1	1
	5001600303	Notomastus lineatus	0	1	0	2	1	4
	5001600601	Barantolla americana	0	0	1	1	0	2
	5001630802	Axiothella rubrocincta	0	0	0	1	0	1
	5001631	Euclymeninae	0	0	1	0	0	1
	5001660303	Pectinaria granulata	2	8	2	4	2	18
	500168	Terebellidae	3	0	0	1	0	4
	50016808	Polycirrus spp.	0	1	1	0	0	2
	500168130201	Lanassa venusta venusta	0	0	0	1	0	1
	5103760201	Natica clausa	2	2	1	1	1	7
	5105030204	Mitrella gouldi	3	0	0	0	0	3
	5105100102	Olivella baetica	0	1	0	0	0	1
	51080102	Turbonilla spp.	0	0	0	1	0	1
	51100601	Aglaja spp.	0	0	0	1	1	2
	5502020201	Nucula tenuis	1	0	0	0	1	2
	5507010201	Crenella decussata	0	0	0	1	0	1
	5515020201	Axinopsida serricata	1	2	4	6	2	15
	5515100102	Mysella tumida	6	8	4	1	0	19
	5515220102	Clinocardium nuttali	2	0	6	3	5	16

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
NG-03	43020101	Tubulanus spp.	0	5	3	0	0	8
	4302010104	Tubulanus pellucidus	0	0	1	0	0	1
	43030205	Micrura spp.	1	5	1	5	0	12
	47	Nematoda	0	0	0	1	0	1
	5001021	Harmothoinae	0	1	0	1	0	2
	5001060101	Pholoe minuta	0	0	0	2	0	2
	5001131101	Eulalia (Eumida) sanguinea	0	1	0	1	0	2
	5001131402	Phyllodoce (Aponaitides) hartmanae	0	0	0	0	1	1
	5001230308	Syllis elongata	1	3	2	1	0	7
	5001230703	Exogone lourei	0	1	0	0	0	1
	50012404	Nereis spp.	0	1	0	0	0	1
	5001240404	Nereis procera	0	0	0	0	1	1
	5001240501	Platynereis bicanaliculata	1	0	1	2	0	4
	5001250103	Nephtys caeca	0	1	0	0	2	3
	5001250111	Nephtys ferruginea	0	1	0	0	0	1
	5001260103	Sphaerodoropsis sphaerulifer	1	0	0	0	2	3
	5001280101	Glycinde picta	0	3	1	0	0	4
	500128029999	Goniada brunnea/maculata	0	1	1	0	0	2
	50012901	Onuphis spp.	1	0	0	0	0	1
	5001290111	Onuphis elegans	1	0	0	0	0	1
	5001290202	Diopatra ornata	0	0	0	1	0	1
	5001310197	Lumbrineris sp. gr. 1	0	0	0	1	0	1
	5001360201	Protodorvillea gracilis	0	0	2	0	0	2
	5001360504	Schistomeringos rudolphi	0	1	0	0	0	1
	5001400102	Leitoscoloplos pugettensis	0	0	3	2	0	5
	5001400301	Scoloplos armiger	0	25	21	29	30	105
	5001400311	Scoloplos acmeceps	1	8	0	1	0	10
	500141	Paraonidae	0	0	0	0	1	1
	50014102	Acesta/Aricidea spp.	0	0	0	0	1	1
	5001410201	Aricidea suecica	0	3	2	0	0	5
	5001430506	Prionospio steenstrupi	1	0	0	0	0	1
	5001430701	Spio filicornis	0	0	2	0	2	4
	5001431001	Spiophanes bombyx	0	0	0	1	0	1
	5001490302	Spiochaetopterus costarum	5	3	4	0	0	12
	5001490401	Mesochaetopterus taylori	0	1	0	1	0	2
	50015003	Tharyx spp.	0	0	1	0	2	3
	50015004	Chaetozone spp.	2	1	0	1	0	4
	50015804	Travisia spp.	0	0	0	0	2	2
	5001580401	Travisia brevis	0	3	1	2	0	6
	5001600303	Notomastus lineatus	0	3	1	0	0	4
	5001600501	Decamastus gracilis	0	0	0	0	1	1
	5001630903	Praxillella affinis	0	0	0	0	3	3
	5001631	Euclymeninae	0	3	6	1	1	11
	5001660303	Pectinaria granulata	0	1	4	6	0	11
	500168	Terebellidae	0	4	7	4	0	15
	50016807	Pista spp.	0	1	0	0	0	1
	5001680701	Pista cristata	0	1	0	0	0	1
	50016808	Polycirrus spp.	2	14	11	15	4	46
	5001681501	Laphania boecki	1	2	2	5	4	14
	51021003	Margarites spp.	29	44	15	20	29	137

TABLE F-2. (CONTINUED)

Station NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total	
NG-03								
		828	1087	798	895	969	4577	Sum
		8	11	8	9	10	46	Ave
		2051	3041	1600	2113	2401	54942	Var
		0	0	0	0	0	1	Min
		403	493	323	404	420	2043	Max

Number of Observations: 100

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
NG-04	5110120101	Haminoea vesicula	0	0	1	0	0	1
	5502020201	Nucula tenuis	0	3	1	1	0	5
	5502040203	Nuculana fossa	0	0	3	0	0	3
	5507010201	Crenella decussata	0	0	1	1	0	2
	5507010301	Megacrenella columbiana	0	1	0	0	0	1
	55070106	Modiolus spp.	1	0	0	0	0	1
	5507010603	Modiolus rectus	0	0	1	0	0	1
	5515010101	Parvilucina tenuisculpta	10	4	6	7	7	34
	5515010201	Lucinoma acutilineata	0	0	0	0	1	1
	5515020201	Axinopsida serricata	44	21	5	24	35	129
	55151001	Mysella spp.	0	0	32	0	0	32
	5515100102	Mysella tumida	46	45	0	9	13	113
	55152201	Clinocardium spp.	0	0	83	0	0	83
	5515220101	Clinocardium ciliatum	37	0	0	0	6	43
	5515220102	Clinocardium nuttali	0	55	0	5	1	61
	5515250104	Spisula falcata	5	2	7	4	1	19
	5515290201	Solen sicarius	0	0	2	0	0	2
	55153101	Macoma spp.	0	0	0	1	7	8
	5515310106	Macoma obliqua	14	9	0	0	0	23
	5515310114	Macoma nasuta	4	0	0	0	0	4
	5515310116	Macoma balthica	0	0	4	0	1	5
	5515310202	Tellina nuculoides	2	0	1	0	1	4
	5515310204	Tellina modesta	15	33	11	2	1	62
	5515350101	Semele rubropicta	0	0	0	1	0	1
	5515470101	Transenella tantilla	0	0	0	1	0	1
	5515470201	Saxidomus giganteus	0	20	18	0	0	38
	5515470501	Psephidia lordi	92	132	126	188	150	688
	5515470701	Protothaca staminea	1	3	4	0	2	10
	5517010201	Mya arenaria	3	1	0	1	0	5
	55200502	Lyonsia spp.	0	0	1	0	0	1
	5520050201	Lyonsia arenosa	1	1	0	0	0	2
	611103	Cylindroleberididae	0	0	0	1	0	1
	6111070301	Euphilomedes carcharodonta	170	111	110	175	160	726
	6154050101	Diastylis alaskensis	1	0	0	0	1	2
	6154070105	Campylaspis hartae	0	0	0	0	1	1
	61570201	Leptochelia spp.	1	0	0	0	0	1
	6157020103	Leptochelia dubia	10	14	8	9	20	61
	61620202	Synidotea spp.	0	0	1	0	0	1
	6169020112	Ampelisca cristata	0	1	0	0	0	1
	6169020113	Ampelisca hancocki	1	0	0	0	0	1
	6169020208	Byblis millsi	1	1	0	0	0	2
	61690602	Aoroides spp	2	0	2	0	0	4
	61691502	Corophium spp.	0	1	0	0	0	1
	61692602	Photis spp.	1	10	0	0	1	12
	6169260201	Photis brevipes	1	0	0	0	0	1
	61692603	Protomedeia spp.	0	0	1	0	0	1
	61693414	Hippomedon spp.	0	0	0	0	2	2
	6169342903	Orchomene pacifica	1	0	0	1	5	7
	6169342904	Orchomene pinquis	0	3	4	0	0	7
	6169371403	Synchelidium rectipalmum	3	1	0	1	1	6

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
NG-06	3754020201	Ptilosarcus gurneyi	7	8	18	10	8	51
	37590401	Halcampa spp	0	0	0	2	1	3
	4302010104	Tubulanus pellucidus	2	0	0	2	3	7
	43030204	Lineus spp.	0	0	0	1	0	1
	43030205	Micrura spp.	5	4	0	5	5	19
	43060501	Amphiporus spp.	0	1	0	0	0	1
	47	Nematoda	0	1	0	0	1	2
	5001020603	Gattyana cirrosa	1	0	2	1	0	4
	5001021	Harmothoinae	0	0	1	0	0	1
	5001022301	Tenonia kitsapensis	0	0	0	1	0	1
	5001060101	Pholoe minuta	2	2	0	0	2	6
	5001060301	Sthenelais berkeleyi	0	0	0	0	1	1
	5001130102	Phyllodoce (Anaitides) groenlandica	0	0	1	0	2	3
	5001130112	Phyllodoce (Anaitides) longipes	0	0	0	0	1	1
	50011302	Eteone spp.	1	0	0	0	1	2
	5001130205	Eteone longa	0	1	0	1	2	4
	5001131101	Eulalia (Eumida) sanguinea	4	0	2	0	2	8
	5001210102	Gyptis brevipalpa	0	0	0	0	1	1
	5001230308	Syllis elongata	1	1	0	3	3	8
	5001230312	Syllis hyalina	0	1	0	0	0	1
	5001230703	Exogone lourei	3	2	0	1	0	6
	5001240501	Platynereis bicanaliculata	4	0	2	0	2	8
	5001250102	Nephtys ciliata	0	3	0	0	0	3
	5001250103	Nephtys caeca	0	0	1	0	0	1
	5001250111	Nephtys ferruginea	12	3	6	8	3	32
	5001260103	Sphaerodoropsis sphaerulifer	13	7	4	2	20	46
	5001270101	Glycera capitata	0	3	0	3	2	8
	5001280101	Glycinde picta	8	4	3	8	9	32
	5001280103	Glycinde armigera	0	2	0	2	2	6
	50012901	Onuphis spp.	2	1	0	5	2	10
	5001290111	Onuphis elegans	6	4	0	2	0	12
	50013101	Lumbrineris spp.	1	0	0	0	1	2
	5001310109	Lumbrineris luti	5	4	1	7	15	32
	5001310118	Lumbrineris cruzensis	2	0	0	2	0	4
	5001310128	Lumbrineris limicola	1	0	0	0	0	1
	5001310195	Lumbrineris sp. gr. 3	1	0	0	1	0	2
	5001310197	Lumbrineris sp. gr. 1	21	3	4	23	10	61
	5001400102	Leitoscoloplos pugettensis	37	17	10	23	36	123
	5001400301	Scoloplos armiger	5	25	9	0	3	42
	5001400311	Scoloplos acmeceps	0	1	0	1	0	2
	5001400510	Orbinia (Phylo) felix	0	1	0	2	1	4
	5001430431	Polydora cardalia	0	1	0	0	0	1
	50014305	Prionospio spp.	0	0	0	0	1	1
	5001430506	Prionospio steenstrupi	8	9	4	11	7	39
	5001430599	Prionospio multibranchiata	1	0	0	1	0	2
	5001430703	Spio cirrifera	0	1	0	0	0	1
	5001440105	Magelona longicornis	0	0	0	1	0	1
	5001490302	Spiochaetopterus costarum	0	1	7	0	9	17
	50014904	Mesochaetopterus spp.	0	0	1	0	1	2
	5001490401	Mesochaetopterus taylori	0	0	1	3	0	4

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
NG-06	5515220201	Serripes groenlandicus	3	0	0	1	2	6
	5515250104	Spisula falcata	2	0	1	0	0	3
	5515290201	Solen sicarius	4	0	1	0	1	6
	5515310102	Macoma elimata	4	0	0	3	0	7
	5515310106	Macoma obliqua	4	4	1	5	2	16
	5515310111	Macoma yoldiformis	0	1	0	0	0	1
	5515310112	Macoma carlottensis	0	1	0	1	0	2
	5515310116	Macoma balthica	0	3	1	2	1	7
	5515310202	Tellina nuculoides	1	1	1	1	0	4
	5515310204	Tellina modesta	2	3	2	3	2	12
	5515470201	Saxidomus giganteus	1	8	5	2	6	22
	5515470501	Psephidia lordi	62	125	96	62	83	428
	5515470701	Protothaca staminea	0	1	1	2	0	4
	5517010201	Mya arenaria	6	4	7	4	2	23
	5520020102	Pandora filosa	0	1	2	0	2	5
	5520050201	Lyonsia arenosa	4	6	2	1	3	16
	5520100108	Cardiomya californica	0	4	1	4	0	9
	611103	Cylindroleberididae	0	0	0	0	1	1
	6111060103	Rutiderma lomae	7	3	1	5	10	26
	6111070301	Euphilomedes carcharodonta	174	190	153	124	119	760
	6111070303	Euphilomedes producta	12	5	3	2	7	29
	61450101	Nebalia spp.	1	0	1	0	0	2
	6154040202	Eudorella pacifica	1	0	0	0	0	1
	6154050101	Diastylis alaskensis	2	1	0	0	1	4
	6154070105	Campylaspis hartae	1	2	0	0	0	3
	61570201	Leptochelia spp.	8	1	0	0	6	15
	6157020103	Leptochelia dubia	50	20	19	31	0	120
	6160011601	Haliophasma geminata	0	3	1	0	5	9
	6169	Gammaridea	1	1	0	0	0	2
	6169020113	Ampelisca hancocki	0	0	0	1	0	1
	6169020208	Byblis millsi	0	5	3	2	1	11
	61690602	Aoroides spp	3	1	0	0	1	5
	6169211008	Melita desdichada	1	1	0	0	0	2
	61692602	Photis spp.	1	0	1	1	0	3
	61693414	Hippomedon spp.	0	0	0	1	0	1
	61693429	Orchomene spp.	1	0	0	0	0	1
	6169342903	Orchomene pacifica	0	2	0	4	1	7
	61693708	Monoculodes spp.	1	0	0	0	0	1
	6169371402	Synchelidium shoemakeri	0	0	2	2	2	6
	6169371502	Westwoodilla caecula	7	0	2	7	10	26
	6169420602	Metaphoxus fultoni	1	0	0	0	0	1
	6169421504	Rhepoxynius abronius	0	1	0	0	1	2
	61694303	Parapleustes spp.	1	0	0	0	0	1
	61830402	Callianassa spp.	1	1	2	0	1	5
	6188030105	Cancer gracilis	0	0	1	0	0	1
	61890604	Pinnixa spp.	1	0	0	1	0	2
	7200020104	Golfingia pugett[illegible]sis	0	0	1	0	1	2
	77	Phoronida	0	0	5	0	0	5
	7700010102	Phoronopsis harmeri	0	1	0	0	0	1
	8127011	Ophiolepidinae	1	0	0	0	0	1

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
NG-10	3754020201	Ptilosarcus gurneyi	0	1	0	1	0	2
	43020101	Tubulanus spp.	1	3	0	6	11	21
	4302010104	Tubulanus pellucidus	1	1	0	3	0	5
	430302	Lineidae	0	0	7	0	0	7
	43030202	Cerebratulus spp.	0	1	0	0	1	2
	43030204	Lineus spp.	0	0	3	0	0	3
	43030205	Micrura spp.	6	3	7	11	5	32
	430605	Amphiporidae	0	0	0	0	1	1
	43060501	Amphiporus spp.	7	2	0	0	5	14
	43060602	Tetrastemma spp.	0	0	2	6	1	9
	47	Nematoda	0	1	0	2	0	3
	5001020810	Harmothoe lunulata	0	0	2	0	0	2
	5001060101	Pholoe minuta	1	1	7	8	11	28
	5001130102	Phyllodoce (Anaitides) groenlandica	2	2	2	2	0	8
	5001130112	Phyllodoce (Anaitides) longipes	0	0	0	1	0	1
	5001130114	Phyllodoce (Anaitides) williamsi	0	0	0	2	0	2
	50011302	Eteone spp.	2	0	0	0	0	2
	5001130205	Eteone longa	0	1	1	0	0	2
	5001131101	Eulalia (Eumida) sanguinea	0	1	3	0	1	5
	5001210102	Gyptis brevipalpa	0	0	0	0	1	1
	5001210801	Micropodarke dubia	0	0	0	1	1	2
	5001211101	Heteropodarke heteromorpha	0	0	1	0	0	1
	5001230308	Syllis elongata	16	0	10	6	2	34
	5001230703	Exogone lourei	1	0	0	0	0	1
	5001240501	Platynereis bicanaliculata	9	62	13	53	81	218
	5001250103	Nephtys caeca	0	7	1	5	5	18
	5001250111	Nephtys ferruginea	4	3	2	1	1	11
	5001260103	Sphaerodoropsis sphaerulifer	2	0	1	0	0	3
	5001270101	Glycera capitata	4	0	0	0	0	4
	5001270104	Glycera americana	1	0	0	2	0	3
	5001280101	Glycinde picta	4	9	12	8	7	40
	5001280103	Glycinde armigera	1	1	0	5	3	10
	500129	Onuphidae	0	0	0	0	1	1
	50012901	Onuphis spp.	0	0	1	1	0	2
	5001290111	Onuphis elegans	4	3	1	0	3	11
	5001290202	Diopatra ornata	1	0	2	2	0	5
	50013101	Lumbrineris spp.	0	0	1	0	0	1
	5001310109	Lumbrineris luti	3	0	1	1	0	5
	5001310194	Lumbrineris sp. gr. 4	0	1	1	1	0	3
	5001310195	Lumbrineris sp. gr. 3	0	0	1	0	0	1
	5001310197	Lumbrineris sp. gr. 1	0	0	1	1	0	2
	5001360201	Protodorvillea gracilis	34	2	10	24	11	81
	5001360206	Protodorvillea pugettensis	0	1	0	0	0	1
	5001360504	Schistomeringos rudolphi	0	0	2	1	2	5
	5001400101	Leitoscoloplos panamensis	1	0	0	0	1	2
	5001400102	Leitoscoloplos pugettensis	4	1	9	4	4	22
	5001400301	Scoloplos armiger	4	0	4	7	2	17
	5001400311	Scoloplos acmeceps	1	0	0	2	1	4
	5001410201	Aricidea suecica	0	1	0	0	0	1
	50014305	Prionospio spp.	0	0	0	5	1	6

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa, Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
NG-10	55090506	Delectopecten spp.	0	1	0	0	1	2
	5509090101	Pododesmus macroschisma	3	6	0	0	0	9
	5515010101	Parvilucina tenuisculpta	13	14	8	13	12	60
	5515010201	Lucinoma acutilineata	1	1	0	0	0	2
	5515020201	Axinopsida serricata	61	28	33	22	23	167
	5515100102	Mysella tumida	10	89	78	271	162	610
	55152201	Clinocardium spp.	1	0	0	3	0	4
	5515220102	Clinocardium nuttali	6	19	5	33	10	73
	5515220201	Serripes groenlandicus	22	0	7	1	0	30
	5515250104	Spisula falcata	0	1	0	3	3	7
	5515310106	Macoma obliqua	9	65	20	55	34	183
	5515310116	Macoma balthita	0	29	2	15	15	61
	5515310202	Tellina nuculoides	0	0	0	1	1	2
	5515310204	Tellina modesta	2	24	6	28	15	75
	5515470101	Transenella tantilla	3	1	3	10	1	18
	5515470201	Saxidomus giganteus	9	106	72	177	107	471
	5515470501	Psephidia lordi	92	16	56	47	28	239
	5515470701	Protothaca staminea	0	15	4	11	7	37
	5517010201	Mya arenaria	11	2	8	6	1	28
	5520050201	Lyonsia arenosa	2	1	1	2	0	6
	6111060103	Rutiderma lomae	3	0	0	0	1	4
	6111070301	Euphilomedes carcharodonta	196	67	189	265	201	918
	6111070303	Euphilomedes producta	3	0	0	0	0	3
	61340201	Balanus spp.	0	0	0	0	1	1
	61450101	Nebalia spp.	0	23	0	0	0	23
	61570201	Leptochelia spp.	4	0	7	0	6	17
	6157020103	Leptochelia dubia	44	69	71	180	107	471
	6160011601	Heliophasma geminata	3	0	1	0	0	4
	61620202	Synidotea spp.	0	1	1	2	2	6
	616312	Munnidae	0	0	0	1	1	2
	616504	Bopyridae	0	0	4	0	0	4
	6169020208	Byblis millsi	4	0	0	1	1	6
	6169040118	Ampithoe lacertosa	0	1	0	0	0	1
	61690404	Perampithoe spp.	0	1	0	0	0	1
	61690602	Aoroides spp	4	43	1	3	4	55
	6169060203	Aoroides inermis	11	49	4	27	4	95
	6169060204	Aoroides spinosus	0	150	0	8	7	165
	6169060205	Aoroides exilis	3	37	8	46	6	100
	61691202	Calliopius spp.	0	0	0	1	0	1
	61691502	Corophium spp.	0	1	0	1	0	2
	6169201208	Pontogeneia rostrata	0	5	0	1	0	6
	6169201307	Rhachotropis oculata	2	0	0	0	0	2
	61692110	Melita spp.	0	2	0	2	0	4
	6169211003	Melita dentata	0	9	0	0	6	15
	6169211008	Melita desdichada	1	18	3	15	6	43
	61692602	Photis spp.	0	19	7	64	15	105
	6169260201	Photis brevipes	3	101	26	179	47	356
	6169270202	Ischyrocerus anguipes	0	2	0	2	1	5
	61693414	Hippomedon spp.	3	0	0	0	0	3
	6169342903	Orchomene pacifica	1	0	0	0	0	1

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa, Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
PS-02	3754020201	Ptilosarcus gurneyi	0	0	1	0	0	1
	37590101	Edwardsia spp.	0	0	0	0	1	1
	3906	Polycladida	0	0	1	0	0	1
	4302010104	Tubulanus pellucidus	1	1	0	0	0	2
	43030205	Micrura spp.	1	2	3	2	1	9
	430606029998	Tetrastemma sp. C (Everett Harbor only)	1	0	0	0	2	3
	47	Nematoda	0	0	0	0	1	1
	5001021703	Hesperonoe laevis	0	0	0	1	0	1
	5001130102	Phyllodoce (Anaitides) groenlandica	0	0	0	1	0	1
	50011302	Eteone spp.	0	1	0	0	1	2
	5001130205	Eteone longa	0	0	1	0	1	2
	5001240404	Nereis procera	0	0	0	1	0	1
	5001250111	Nephtys ferruginea	9	14	8	9	9	49
	5001270101	Glycera capitata	2	1	3	2	1	9
	5001270104	Glycera americana	0	1	0	0	0	1
	500128029999	Goniada brunnea/maculata	2	2	1	1	1	7
	50012901	Onuphis spp.	0	1	0	1	0	2
	5001310109	Lumbrineris luti	12	18	24	12	12	78
	5001310197	Lumbrineris sp. gr. 1	12	14	6	8	17	57
	5001400101	Leitoscoloplos panamensis	0	0	1	1	1	3
	5001400102	Leitoscoloplos pugettensis	13	34	22	36	13	118
	5001400301	Scoloplos armiger	0	4	0	1	5	10
	5001400510	Orbinia (Phylo) felix	2	0	2	0	1	5
	5001410201	Aricidea suecica	0	6	1	0	2	9
	5001430429	Polydora brachycephala	0	0	0	0	1	1
	5001430431	Polydora cardalia	0	0	4	1	0	5
	5001430502	Prionospio cirrifera	1	0	0	0	2	3
	5001430506	Prionospio steenstrupi	0	4	0	2	0	6
	5001430599	Prionospio multibranchiata	0	3	0	0	2	5
	5001490302	Spiochaetopterus costarum	4	5	2	0	2	13
	5001490401	Mesochaetopterus taylori	1	0	0	0	0	1
	50015003	Tharyx spp.	0	1	1	0	1	3
	5001580607	Ophelina acuminata	3	7	1	4	15	30
	50016004	Mediomastus spp.	1	2	2	0	6	11
	5001600501	Decamastus gracilis	2	0	0	0	1	3
	5001600601	Barantolla americana	1	1	2	0	2	6
	5001630903	Praxillella affinis	1	0	0	0	0	1
	5001631	Euclymeninae	3	3	0	1	2	9
	5001631001	Rhodine bitorquata	1	0	0	0	0	1
	5001660303	Pectinaria granulata	4	2	7	4	10	27
	5001660304	Pectinaria californiensis	0	1	0	1	0	2
	5001670208	Ampharete acutifrons	0	0	0	0	1	1
	5001670401	Lysippe labiata	0	1	0	0	0	1
	500168	Terebellidae	1	0	0	0	0	1
	50016807	Pista spp.	0	4	1	0	2	7
	5001680701	Pista cristata	0	1	0	0	1	2
	50016808	Polycirrus spp.	0	1	0	0	1	2
	500168130201	Lanassa venusta venusta	0	0	0	1	0	1
	5001690101	Terebellides stroemi	0	1	0	0	0	1
	50017001	Chone spp.	0	0	0	1	0	1

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total	
PS-02			0	0	0	0	0	1	Min
			101	219	186	246	195	947	Max

Number of Observations: 96

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
PS-03	50016312	Clymenura spp.	0	0	1	0	0	1
	5001660303	Pectinaria granulata	44	51	41	50	61	247
	5001660304	Pectinaria californiensis	1	0	1	0	1	3
	50016702	Ampharete spp.	6	2	0	1	0	9
	5001670208	Ampharete acutifrons	3	3	2	8	12	28
	5001670401	Lysippe labiata	3	2	0	0	1	6
	5001670804	Asabellides lineata	1	0	0	0	0	1
	500168	Terebellidae	0	1	0	0	0	1
	50016807	Pista spp.	19	27	1	4	14	65
	5001680701	Pista cristata	1	4	3	2	0	10
	5001680710	Pista brevibranchiata	0	1	0	0	0	1
	50016808	Polycirrus spp.	0	3	0	0	1	4
	500168130201	Lanassa venusta venusta	0	1	0	0	0	1
	5001690101	Terebellides stroemi	3	1	1	1	3	9
	5001700204	Euchone incolor	5	0	0	0	0	5
	51032001	Alvania spp.	1	0	2	2	3	8
	5103760201	Natica clausa	0	1	0	1	1	3
	5105030204	Mitrella gouldi	1	7	2	1	9	20
	51080102	Turbonilla spp.	1	1	0	0	0	2
	51100601	Aglaja spp.	1	1	1	0	1	4
	5502020201	Nucula tenuis	2	1	2	2	4	11
	55070106	Modiolus spp.	0	0	1	0	0	1
	5515010101	Parvilucina tenuisculpta	1	0	0	0	1	2
	5515020201	Axinopsida serricata	19	24	16	22	16	97
	5515100102	Mysella tumida	1	1	0	0	4	6
	55152201	Clinocardium spp.	0	1	0	0	0	1
	5515220102	Clinocardium nuttali	6	7	14	26	20	73
	5515220201	Serripes groenlandicus	1	0	1	0	0	2
	5515220301	Nemocardium centifilosum	0	0	2	0	0	2
	5515250104	Spisula falcata	4	1	5	4	0	14
	5515290201	Solen sicarius	1	0	2	3	0	6
	5515310102	Macoma elimata	3	2	1	3	1	10
	5515310106	Macoma obliqua	0	4	0	0	0	4
	5515310116	Macoma balthica	21	15	25	21	36	118
	5515310202	Tellina nuculoides	0	0	1	0	1	2
	5515470201	Saxidomus giganteus	1	0	1	1	0	3
	5515470501	Psephidia lordi	25	55	44	62	48	234
	5515470701	Protothaca staminea	1	1	1	1	1	5
	5517010201	Mya arenaria	0	0	0	1	0	1
	5520020102	Pandora filosa	0	0	0	0	1	1
	5520020103	Pandora bilirata	0	1	0	0	0	1
	5520050201	Lyonsia arenosa	2	3	2	2	2	11
	5520080103	Asthenothaerus villosior	0	1	0	0	0	1
	6111060103	Rutiderma lomae	1	2	0	0	0	3
	6111070301	Euphilomedes carcharodonta	55	59	75	77	81	347
	6111070303	Euphilomedes producta	45	33	12	14	15	119
	6160011601	Haliophasma geminata	2	0	0	1	0	3
	6169020125	Ampelisca brevisimulata	0	1	0	0	0	1
	6169020135	Ampelisca careyi	2	2	1	2	2	9
	61692603	Protomedeia spp.	1	0	0	0	0	1

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa, Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
PS-04	3754020201	Ptilosarcus gurneyi	2	0	0	0	4	6
	37590401	Halcampa spp	0	0	0	1	0	1
	4302010104	Tubulanus pellucidus	0	0	2	0	4	6
	43030204	Lineus spp.	0	2	0	0	0	2
	43030205	Micrura spp.	0	2	2	0	2	6
	47	Nematoda	1	0	0	0	0	1
	5001060101	Pholoe minuta	0	1	0	0	0	1
	5001130102	Phyllodoce (Anaitides) groenlandica	1	1	0	1	0	3
	50011302	Eteone spp.	1	1	0	1	1	4
	5001130205	Eteone longa	0	0	0	0	3	3
	50011311	Eulalia (Eumida) spp.	0	0	0	1	0	1
	5001131101	Eulalia (Eumida) sanguinea	1	0	0	0	1	2
	50011314	Phyllodoce spp.	1	0	1	0	0	2
	5001131402	Phyllodoce (Aponaitides) hartmanae	0	0	1	0	1	2
	5001131411	Phyllodoce (Anaitides) cuspidata	0	0	0	1	0	1
	50012303	Syllis spp.	0	0	0	0	1	1
	50012307	Exogone spp.	1	0	0	0	0	1
	5001230703	Exogone lourei	3	5	3	3	10	24
	5001250104	Nephtys cornuta	0	0	1	0	0	1
	5001250111	Nephtys ferruginea	0	5	1	3	1	10
	5001250121	Nephtys assignis	0	1	0	0	0	1
	5001260103	Sphaerodoropsis sphaerulifer	2	0	3	0	3	8
	5001270101	Glycera capitata	11	12	4	4	10	41
	5001270104	Glycera americana	0	0	0	0	1	1
	500128029999	Goniada brunnea/maculata	2	2	3	5	4	16
	50012901	Onuphis spp.	0	2	0	0	0	2
	50013101	Lumbrineris spp.	0	4	0	0	0	4
	5001310109	Lumbrineris luti	4	7	11	9	16	47
	5001310195	Lumbrineris sp. gr. 3	0	1	0	0	0	1
	5001310197	Lumbrineris sp. gr. 1	16	18	10	14	16	74
	500133010402	Driloneris falcata minor	0	1	0	0	0	1
	5001400102	Leitoscoloplos pugettensis	1	4	3	6	5	19
	5001400301	Scoloplos armiger	0	0	0	1	0	1
	5001400311	Scoloplos acmeceps	0	0	2	0	0	2
	5001410201	Aricidea suecica	1	1	0	1	0	3
	50014305	Prionospio spp.	1	1	0	1	0	3
	5001430502	Prionospio cirrifera	1	0	0	0	0	1
	5001430506	Prionospio steenstrupi	1	6	6	0	2	15
	5001430599	Prionospio multibranchiata	0	0	0	0	2	2
	5001490302	Spiochaetopterus costarum	7	3	6	0	10	26
	5001490401	Mesochaetopterus taylori	0	1	0	0	0	1
	50015004	Chaetozone spp.	1	1	1	0	1	4
	5001580607	Ophelina acuminata	1	3	0	0	0	4
	5001600302	Notomastus tenuis	0	1	1	0	1	3
	50016004	Mediomastus spp.	0	0	1	0	0	1
	50016303	Maldane spp.	0	0	0	0	1	1
	50016309	Praxillella spp.	0	1	0	0	0	1
	5001630901	Praxillella gracilis	0	1	0	0	0	1
	5001630903	Praxillella affinis	1	0	1	3	2	7
	5001631	Euclymeninae	0	1	12	2	5	20

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total	
PS-04	5520050201	Lyonsia arenosa	0	2	4	1	1	8	
	5520050205	Lyonsia pugetensis	1	0	0	0	0	1	
	5520080103	Asthenothaerus villosior	0	1	1	0	0	2	
	611103	Cylindroleberididae	0	1	1	0	0	2	
	6111060103	Rutiderma lomae	1	2	1	1	9	14	
	6111070301	Euphilomedes carcharodonta	91	94	67	67	47	366	
	6111070303	Euphilomedes producta	38	36	23	56	76	229	
	6118070299	Aetideus divergens	0	0	1	0	0	1	
	6154070103	Campylaspis rubicunda	0	1	0	0	1	2	
	6154070105	Campylaspis hartae	0	1	0	1	1	3	
	6157020103	Leptochelia dubia	2	4	0	0	1	7	
	6157020203	Leptognathia longiremus	0	0	1	0	1	2	
	6157020204	Leptognathia brevimana	0	1	0	0	0	1	
	6160011601	Haliophasma geminata	1	1	0	1	0	3	
	61690201	Ampelisca spp.	0	0	0	1	0	1	
	6169020111	Ampelisca agassizi	0	0	0	0	1	1	
	6169020113	Ampelisca hancocki	0	0	0	1	1	2	
	6169020135	Ampelisca careyi	1	0	0	0	1	2	
	6169020208	Byblis millsi	3	0	3	4	2	12	
	61690602	Aoroides spp	0	0	0	0	0	0	
	61690602	Aoroides spp	0	0	0	0	1	1	
	616934	Lysianassidae	1	0	0	0	0	1	
	61693414	Hippomedon spp.	0	2	0	0	0	2	
	6169342802	Opisa tridentata	2	0	1	0	0	3	
	6169342903	Orchomene pacifica	1	0	2	1	1	5	
	6169345701	Prachynella lodo	0	0	0	0	1	1	
	6169371502	Westwoodilla caecula	0	1	1	0	1	3	
	61830402	Callianassa spp.	0	0	3	0	0	3	
	61890604	Pinnixa spp.	1	0	2	0	2	5	
	7200020104	Golfingia pugettensis	2	0	1	1	0	4	
	7700010102	Phoronopsis harmeri	0	0	1	0	1	2	
	8129030110	Amphiodia psara	0	0	0	0	1	1	
	8401	Ascidiacea	0	0	0	0	1	1	
	8406030402	Eugyra arenosa	0	0	1	2	0	3	
			375	529	438	373	476	2191	Sum
			3	4	3	3	4	16	Ave
			102	176	106	89	104	2576	Var
			0	0	0	0	0	0	Min
			91	94	70	67	76	366	Max

Number of Observations: 134

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
SD-02	3754020201	Ptilosarcus gurneyi	1	3	6	7	3	20
	430302	Lineidae	0	1	0	0	0	1
	43030204	Lineus spp.	0	0	2	0	0	2
	43030205	Micrura spp.	6	9	3	4	5	27
	430606029998	Tetrastemma sp. C (Everett Harbor only)	1	0	0	0	0	1
	5001020810	Harmothoe lunulata	1	0	2	4	0	7
	5001130102	Phyllodoce (Anaitides) groenlandica	0	2	0	0	0	2
	50011302	Eteone spp.	1	1	0	0	0	2
	5001130205	Eteone longa	0	8	1	3	1	13
	5001131402	Phyllodoce (Aponaitides) hartmanae	0	0	0	1	0	1
	5001210102	Gyptis brevipalpa	0	0	0	0	1	1
	5001230308	Syllis elongata	0	1	1	0	0	2
	5001250103	Nephtys caeca	0	0	0	0	2	2
	5001250111	Nephtys ferruginea	4	2	5	4	2	17
	5001270101	Glycera capitata	1	3	1	0	2	7
	500128029999	Goniada brunnea/maculata	0	0	0	0	1	1
	50012901	Onuphis spp.	1	0	0	0	1	2
	5001290111	Onuphis elegans	0	1	0	0	0	1
	5001310109	Lumbrineris luti	9	8	5	6	6	34
	5001310197	Lumbrineris sp. gr. 1	8	11	7	7	9	42
	5001400102	Leitoscoloplos pugettensis	11	10	9	2	10	42
	5001400301	Scoloplos armiger	0	0	3	1	2	6
	5001410201	Aricidea suecica	2	18	9	11	5	45
	5001430431	Polydora cardalia	5	1	2	2	1	11
	5001430506	Prionospio steenstrupi	3	4	2	1	0	10
	5001430703	Spio cirrifera	1	1	0	3	1	6
	5001431004	Spiophanes berkelyorum	1	0	0	0	0	1
	5001490302	Spiochaetopterus costarum	18	7	11	12	7	55
	50014904	Mesochaetopterus spp.	0	0	2	0	0	2
	5001490401	Mesochaetopterus taylori	7	13	4	13	4	41
	50015003	Tharyx spp.	2	1	1	0	4	8
	5001580607	Ophelina acuminata	2	2	1	3	1	9
	50016002	Heteromastus spp.	0	1	0	4	2	7
	5001600203	Heteromastus filobranchus	0	0	0	3	0	3
	5001600303	Notomastus lineatus	0	0	0	0	2	2
	50016004	Mediomastus spp.	3	5	2	3	0	13
	5001600601	Barantolla americana	2	1	4	7	0	14
	5001630802	Axiothella rubrocincta	1	1	1	0	1	4
	5001631	Euclymeninae	8	4	2	7	16	37
	5001660303	Pectinaria granulata	0	0	0	2	0	2
	5001660304	Pectinaria californiensis	0	1	1	1	1	4
	5001670214	Ampharete finmarchica	0	0	1	0	1	2
	5001670401	Lysippe labiata	2	1	0	1	1	5
	5001670801	Asabellides sibirica	0	1	0	0	0	1
	500168	Terebellidae	4	3	1	2	0	10
	50016807	Pista spp.	1	2	4	3	0	10
	500168079998	Pista sp. II (Banse 1979)	0	0	0	1	0	1
	50016808	Polycirrus spp.	11	14	2	25	24	76
	5001681002	Thelepus hamatus	1	1	0	0	0	2
	5001681004	Thelepus setosus	0	0	2	0	3	5

TABLE F-2. (CONTINUED)

Station NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total	
SD-02		0	0	0	0	0	1	Min
		198	202	190	162	176	928	Max

Number of Observations: 96

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total
SR-08	43020101	Tubulanus spp.	0	1	0	0	0	1
	430302	Lineidae	7	0	0	0	0	7
	43030202	Cerebratulus spp.	0	1	0	0	4	5
	43030205	Micrura spp.	21	16	28	12	37	114
	430605	Amphiporidae	0	0	1	0	0	1
	43060501	Amphiporus spp.	0	1	2	0	0	3
	5001020810	Harmothoe lunulata	1	0	1	0	0	2
	5001021	Harmothoinae	0	1	1	1	1	4
	5001060101	Pholoe minuta	0	0	0	1	2	3
	5001130102	Phyllodoce (Anaitides) groenlandica	0	0	0	1	0	1
	50011303	Eulalia (Eulalia) spp.	0	0	0	0	1	1
	50011311	Eulalia (Eumida) spp.	0	0	0	0	1	1
	5001131101	Eulalia (Eumida) sanguinea	1	2	1	0	0	4
	5001210102	Gyptis brevipalpa	0	0	0	0	1	1
	5001240501	Platynereis bicanaliculata	0	8	9	3	15	35
	5001250102	Nephtys ciliata	0	0	0	0	1	1
	5001270101	Glycera capitata	0	0	0	1	0	1
	5001280101	Glycinde picta	10	10	15	15	15	65
	5001280103	Glycinde armigera	0	0	0	1	0	1
	5001290202	Diopatra ornata	0	0	1	2	0	3
	5001310109	Lumbrineris luti	7	1	4	7	9	28
	5001310194	Lumbrineris sp. gr. 4	0	1	0	3	0	4
	5001310195	Lumbrineris sp. gr. 3	0	1	0	2	1	4
	5001310197	Lumbrineris sp. gr. 1	5	8	2	4	2	21
	5001400102	Leitoscoloplos pugettensis	1	0	4	5	3	13
	5001400311	Scoloplos acmeceps	0	0	0	0	1	1
	5001410201	Aricidea suecica	0	1	1	1	7	10
	50014305	Prionospio spp.	0	1	0	4	0	5
	5001430502	Prionospio cirrifera	1	0	2	4	2	9
	5001430506	Prionospio steenstrupi	2	0	3	0	9	14
	5001430599	Prionospio multibranchiata	1	1	15	1	6	24
	5001490302	Spiochaetopterus costarum	0	1	0	1	0	2
	500150	Cirratulidae	0	1	0	3	0	4
	50015003	Tharyx spp.	2	2	3	0	4	11
	50015004	Chaetozone spp.	0	0	1	0	0	1
	5001580202	Armandia brevis	1	2	3	1	0	7
	5001600101	Capitella capitata	1	0	0	0	0	1
	50016002	Heteromastus spp.	5	4	17	3	7	36
	5001600203	Heteromastus filobranchus	3	1	9	2	15	30
	50016004	Mediomastus spp.	3	0	5	5	5	18
	5001600601	Barantolla americana	2	3	9	2	5	21
	5001631	Euclymeninae	0	0	0	1	1	2
	50016311	Euclymene spp.	1	0	0	0	0	1
	5001660303	Pectinaria granulata	12	20	17	21	10	80
	5001660304	Pectinaria californiensis	0	0	1	1	0	2
	500168	Terebellidae	1	0	2	0	1	4
	50016808	Polycirrus spp.	2	0	1	0	3	6
	51032001	Alvania spp.	0	1	6	7	2	16
	5105080101	Nassarius mendicus	0	0	0	2	0	2
	51100601	Aglaja spp.	0	0	1	0	1	2

TABLE F-2. (CONTINUED)

Station	NODC Code	Taxa. Name	Rep1	Rep2	Rep3	Rep4	Rep5	Total	
SR-08									
			193	257	531	385	422	1788	Sum
			2	3	5	4	4	18	Ave
			32	50	185	73	108	1821	Var
			0	0	0	0	0	1	Min
			47	61	214	60	82	364	Max

Number of Observations: 100

APPENDIX G

RELATIVE AND ABSOLUTE ABUNDANCES OF THE FIVE NUMERICALLY DOMINANT TAXA OF BENTHIC INFAUNA AT EACH STATION

APPENDIX G. RELATIVE AND ABSOLUTE ABUNDANCES OF THE FIVE NUMERICALLY DOMINANT TAXA OF BENTHIC INFAUNA AT EACH STATION

PORT SUSAN STATIONS

	Abundance #/m^2		
Taxa	PS-02	PS-03	PS-04
Psephidia lordi	1,894	468	338
Euphilomedes charcharodonta	368	694	732
Clinocardium nuttalli	318		
Leitoscoloplos pugettensis	236		
Axinopsida serricata	186		
Pectinaria granulata		494	562
Euphilomedes producta		238	458
Macoma balthica		236	
Pista spp.			480
Total abundance	3,002	2,130	2,570
Relative abundance (%)	67.9	53.9	58.7

APPENDIX G. (Continued)

SNOHOMISH RIVER AND DELTA STATIONS

Taxa	Abundance #/m^2 SD-01	SD-02	SR-07	SR-08
Archaeomysis grebnitzkii	92			
Grandifoxus grandus	76			
Mya arenaria	26			
Tetrastemma candidum	24			
Macoma balthica	16			
Euphilomedes charcharodonta		1,856		
Axinopsida serricata		1,020		728
Rhepoxynius variatus		338		
Psephidia lordi		226		170
Polycirrus spp.			152	
Macoma nasuta			124	
Tharyx spp.			88	
Macoma carlottensis			62	
Heteromastus filobranchus			52	
Barantolla americana			48	
Photis brevipes				282
Micura spp.				228
Pectinaria granulata				160
Total abundance	234	3,592	374	1,568
Relative abundance %	78.0	68.5	61.4	44.0

APPENDIX H

RELATIVE ABUNDANCE OF OPPORTUNISTIC AND POLLUTION-TOLERANT TAXA OF BENTHIC INFAUNA

APPENDIX H. RELATIVE ABUNDANCE (AS PERCENT FAUNA) OF OPPORTUNISTIC AND POLLUTION-TOLERANT TAXA OF BENTHIC INFAUNA

Taxon	Station		
	PS-02	PS-03	PS-04
Nematoda	0.1		0.1
Phyllodoce (Anaitides) groenlandica	<0.1	0.1	0.1
Eteone spp.	0.1		0.2
Eteone longa	0.1	0.1	0.1
Eulalia (Eumida) sanguinea			0.1
Nephtys ciliata			
Nephtys cornuta			0.1
Nephtys cornuta franciscana			
Glycinde picta		0.2	
Goniada brunnea/maculata	0.3	0.6	0.7
Schistomeringos rudolphi			
Leitoscoloplos pugettensis	5.3	3.4	<0.1
Scoloplos armiger	0.5	0.2	0.1
Prionospio cirrifera	0.1		0.7
Prionospio steenstrupi	0.3	0.5	0.1
Polydora kempi			
Cirratulus cirratus			
Tharyx spp.	0.1	<0.1	
Tharyx multifilis			
Armandia brevis			
Capitella capitata			
Heteromastus spp.			
Heteromastus filiformis			
Heteromastus filibranchus			
Mediomastus spp.	0.5	<0.1	0.8
Oligochaeta			
Mytilus edulis			
Macoma calcarea			
Macoma balthica	1.6	6.0	
Macoma nasuta			1.0
Mya arenaria	0.1	<0.1	0.1
Euphilomedes carcharodonta	8.3	17.6	16.7
Euphilomedes producta	1.3	6.0	10.5
Corophium acherusicum			
Nebalia spp.			
Total	18.7	34.7	31.4

APPENDIX H. (Continued)

Taxon	Station					
	NG-01	NG-02	NG-03	NG-04	NG-06	NG-10
Nematoda	0.1		<0.1		<0.1	<0.1
Phyllodoce (*Anaitides*) *groenlandica*	0.1				<0.1	0.1
Eteone spp.	0.3	0.1			<0.1	<0.1
Eteone longa	0.3	0.2		<0.1	0.1	<0.1
Eulalia (*Eumida*) *sanguinea*	0.1		<0.1	0.1	0.2	0.1
Nephtys ciliata	0.2	0.2		0.2	0.1	
Nephtys cornuta						
Nephtys cornuta franciscana						
Glycinde picta	<0.1	0.6	0.1		0.6	0.5
Goniada brunnea/*maculata*	0.2		<0.1			
Schistomeringos rudolphi			<0.1			0.1
Leitoscoloplos pugettensis	5.2	1.0	0.1	0.3	0.8	0.3
Scoloplos armiger	0.5	10.4	2.3	0.8	<0.1	0.2
Prionospio cirrifera						<0.1
Prionospio steenstrupi	1.2	2.3	<0.1	0.2	0.8	2.1
Polydora kempi						
Cirratulus cirratus						
Tharyx spp.	0.6	0.1	0.1	<0.1	0.1	0.1
Tharyx multifilis	0.1					
Armandia brevis		0.2				0.3
Capitella capitata	0.3					0.1
Heteromastus spp.						
Heteromastus filiformis						<0.1
Heteromastus filibranchus						
Mediomastus spp.	<0.1				<0.1	1.6
Oligochaeta						0.2
Mytilus edulis						
Macoma calcarea						
Macoma balthica	<0.1	0.2		0.2	0.2	0.8
Macoma nasuta	1.3	0.2		0.2		
Mya arenaria	<0.1	0.5	<0.1	0.2	0.5	0.4
Euphilomedes carcharodonta	36.5	48.0	25.0	27.0	15.2	11.6
Euphilomedes producta	1.9		<0.1		0.6	<0.1
Corophium acherusicum						
Nebalia spp.	0.2	0.5	<0.1		<0.1	0.3
Total	49.1	64.5	27.6	29.2	19.2	18.8

APPENDIX I

RANKING OF TIER II PROBLEM AREAS

APPENDIX I. RANKING OF TIER II PROBLEM AREAS

Station	Chemistry		Biology				Ranking							
	90%	HAET	Bioassay	Infauna	Bioaccum.	Pathology	Metals	Organics	Bioassay	Infauna	Bioaccum.	Pathol.	Chemistry Score	Biology Score
ES-03		x		n	n	n	0	3	0	n	n	n	38	0
EW-01	x	x	P	P			2	3	4	4	0	0	63	50
EW-04	x	x	P	P			2	4	4	4	0	0	75	50
EW-07	x	x	P	P			0	4	4	4	0	0	50	50
EW-10		x		P			0	4	4	1	0	0	50	31
EW-11		x	n	n			0	3	n	n	0	0	38	0
EW-12		x					0	3	0	0	0	0	38	0
EW-13	x	x	n	n			2	4	n	n	0	0	75	0
EW-14		x		s			4	4	0	1	0	0	100	6
EW-15		x	n	n			0	3	n	n	0	0	38	0
EW Average													58	21
NG-04		x	P	s			0	3	4	1	0	0	38	31
NG-05		x	n	n			0	3	n	n	0	0	38	0
NG-07		x	n	n			0	2	n	n	0	0	25	0
NG-08		x	n	n			0	2	n	n	0	0	25	0
NG-09		x	n	n			0	3	n	n	0	4	38	50
NG-10		x					0	3	0	0	0	4	38	25
NG-11		x	n	n			0	3	n	n	0	4	38	50
NG-14		x		n	n	n	0	3	0	n	n	n	38	0
NG Average													34	20
OG-01		x	n	n	n	n	0	2	n	n	n	n	25	n
SD-01				P	n	n	0	1	0	4	n	n	13	50
SD-03		x	n	n			0	2	n	n	0	0	25	0
SR-05		x	n	n	n	n	0	3	n	n	n	n	38	n
SR-07				P	n	n	2	0	0	4	n	n	25	50

NOTES:

x = Exceedance of 90th percentile or the highest apparent effects threshold (HAET) for any one chemical. The 90th percentile criterion was applied only to chlorinated phenols/guaiacols and resin acids, which do not have established AET.

s = Statistically significant (P<0.001) biological effect relative to reference area.

P = Statistically significant (P<0.001) biological effect that was above action level for definition of a problem area based on a single indicator.

n = No data.

Numbers in table are tank scores derived from criteria explained in text.

APPENDIX J

APPLICATION OF LAET AND HAET TO EVERETT HARBOR DATA

```
                    SEDIMENT QUALITY VALUES COMPARISON



The sediment quality criteria used for the test are:
     Highest of AMPT, BENA, MICB, and OYST.
     Lowest of AMPT, BENA, MICB, and OYST.

The values used are based on:
     Dry-weight values, no transformation.

Data columns in the output identify, in order from left to right:
    Chemical name
    Concentration
    Measurement units
    Qualifier code of the chemical measurement
    Measurement basis
    Factor by which the concentration exceeds the AET
If an asterisk appears, the AET value was qualified with a "G."



 Survey: EVCHEM    Station: ES-03
================================

   Date: 10/06/86    Sample ID: ES-03G
--------------------------------------

Highest of AMPT, BENA, MICB, and OYST.
--------------------------------------
4-METHYL PHENOL                          1400     PPB       DRY   1.17
BENZOIC ACID                              760     PPB E     DRY   1.17

Lowest of AMPT, BENA, MICB, and OYST.
-------------------------------------
4-METHYL PHENOL                          1400     PPB       DRY   2.09
BENZOIC ACID                              760     PPB E     DRY   1.17
PHENOL                                   1200     PPB Z     DRY   1.79


 Survey: EVCHEM    Station: EW-01
================================

   Date: 10/07/86    Sample ID: EW-01G    Field rep: EW01
---------------------------------------------------------

Highest of AMPT, BENA, MICB, and OYST.
--------------------------------------
4-METHYL PHENOL                          6000     PPB       DRY   5.00
PHENOL                                   1600     PPB Z     DRY   1.33
```

```
  Date: 09/30/86   Sample ID: EW-07G    Field rep: EW07
------------------------------------------------------------

Highest of AMPT, BENA, MICB, and OYST.
--------------------------------------
2-METHYLNAPHTHALENE                         7400    PPB       DRY  11.04
2-METHYLPHENOL                               330    PPB LM    DRY   5.24
2,4-DIMETHYL PHENOL                          100    PPB LM    DRY   3.45
4-METHYL PHENOL                            98000    PPB       DRY  81.67
ACENAPHTHENE                                1800    PPB       DRY   1.84
DIBENZOFURAN                                1600    PPB       DRY   2.96
POLYCYCLIC AROMATIC HYDROCARBON-LIGHT      23000    PPB       DRY   3.77
NAPHTHALENE                                17000    PPB       DRY   7.08

Lowest of AMPT, BENA, MICB, and OYST.
-------------------------------------
2-METHYLNAPHTHALENE                         7400    PPB       DRY  11.04
2-METHYLPHENOL                               330    PPB LM    DRY   5.24
2,4-DIMETHYL PHENOL                          100    PPB LM    DRY   3.45
4-METHYL PHENOL                            98000    PPB       DRY 146.27
ACENAPHTHENE                                1800    PPB       DRY   3.60
ANTHRACENE                                  1200    PPB       DRY   1.25
DIBENZOFURAN                                1600    PPB       DRY   2.96
FLUORENE                                    1400    PPB       DRY   2.59
POLYCYCLIC AROMATIC HYDROCARBON-LIGHT      23000    PPB       DRY   4.42
NAPHTHALENE                                17000    PPB       DRY   8.10
PHENANTHRENE                                1700    PPB       DRY   1.13
PHENOL                                      1000    PPB       DRY   1.49


 Survey: EVCHEM    Station: EW-10
==================================

  Date: 10/01/86    Sample ID: EW-10G    Field rep: EW10
------------------------------------------------------------

Highest of AMPT, BENA, MICB, and OYST.
--------------------------------------
4-METHYL PHENOL                            26000    PPB X     DRY  21.67
PHENOL                                      2900    PPB       DRY   2.42

Lowest of AMPT, BENA, MICB, and OYST.
-------------------------------------
4-METHYL PHENOL                            26000    PPB X     DRY  38.81
CHRYSENE                                    1700    PPB       DRY   1.21
MERCURY                                      0.47   PPM       DRY   1.15
NAPHTHALENE                                 2200    PPB X     DRY   1.05
PHENOL                                      2900    PPB       DRY   4.33


 Survey: EVCHEM    Station: EW-11
==================================

  Date: 09/30/86    Sample ID: EW-11G
------------------------------------------
```

PHENOL	1200	PPB	DRY	1.79
PYRENE	3000	PPB	DRY	1.15
TOTAL ORGANIC CARBON	22.7	PCT	DRY	1.51
ZINC	270	PPM	DRY	1.04

Survey: EVCHEM   Station: EW-14

==================================

Date: 10/01/86   Sample ID: EW-14G   Field rep: EW14

Highest of AMPT, BENA, MICB, and OYST.

2-METHYLNAPHTHALENE	6400	PPB	DRY	9.55
4-METHYL PHENOL	15000	PPB	DRY	12.50
ACENAPHTHENE	5200	PPB	DRY	5.31
ACENAPHTHYLENE	800	PPB	DRY	1.25
ANTHRACENE	6100	PPB	DRY	3.21
BENZOIC ACID	5900	PPB	DRY	9.08
COPPER	1000	PPM	DRY	1.25
DIBENZOFURAN	5000	PPB	DRY	9.26
DIBENZOTHIOPHENE	280	PPB	DRY	1.12
FLUORENE	4300	PPB	DRY	2.39
POLYCYCLIC AROMATIC HYDROCARBON-LIGHT	28000	PPB	DRY	4.59
NAPHTHALENE	7000	PPB	DRY	2.92
PHENOL	1300	PPB	DRY	1.08
ZINC	5900	PPM	DRY	3.69

Lowest of AMPT, BENA, MICB, and OYST.

2-METHYLNAPHTHALENE	6400	PPB	DRY	9.55
DIBENZO(A,H)ANTHRACENE	270	PPB	DRY	1.17
4-METHYL PHENOL	15000	PPB	DRY	22.39
ACENAPHTHENE	5200	PPB	DRY	10.40
ACENAPHTHYLENE	800	PPB	DRY	1.43
ANTHRACENE	6100	PPB	DRY	6.35
ARSENIC	690	PPM	DRY	8.12
BENZO(A)ANTHRACENE	3200	PPB	DRY	2.46
BENZO(A)PYRENE	1700	PPB	DRY	1.06
BENZOIC ACID	5900	PPB	DRY	9.08
CADMIUM	7.9	PPM	DRY	1.36
CHRYSENE	3200	PPB	DRY	2.29
COPPER	1000	PPM	DRY	3.23
DIBENZOFURAN	5000	PPB	DRY	9.26
DIBENZOTHIOPHENE	280	PPB	DRY	1.17
FLUORANTHENE	3400	PPB	DRY	2.00
FLUORENE	4300	PPB	DRY	7.96
POLYCYCLIC AROMATIC HYDROCARBON-HEAVY	23000	PPB	DRY	1.92
INDENO(1,2,3-CD)PYRENE	730	PPB	DRY	1.22
LEAD	520	PPM	DRY	1.73
POLYCYCLIC AROMATIC HYDROCARBON-LIGHT	28000	PPB	DRY	5.38
MERCURY	0.78	PPM	DRY	1.90
NAPHTHALENE	7000	PPB	DRY	3.33
PHENANTHRENE	4800	PPB	DRY	3.20
PHENOL	1300	PPB	DRY	1.94

```
Highest of AMPT, BENA, MICB, and OYST.
-----------------------------------
4-METHYL PHENOL                        9700    PPB X    DRY   8.08
BENZOIC ACID                           2100    PPB X    DRY   3.23

Lowest of AMPT, BENA, MICB, and OYST.
-----------------------------------
4-METHYL PHENOL                        9700    PPB X    DRY  14.48
BENZOIC ACID                           2100    PPB X    DRY   3.23

 Survey: EVCHEM    Station: NG-07
=================================

   Date: 10/02/86    Sample ID: NG-07G
---------------------------------------

Highest of AMPT, BENA, MICB, and OYST.
-----------------------------------
BENZOIC ACID                           1700    PPB X    DRY   2.62

Lowest of AMPT, BENA, MICB, and OYST.
-----------------------------------
BENZOIC ACID                           1700    PPB X    DRY   2.62

 Survey: EVCHEM    Station: NG-08
=================================

   Date: 10/02/86    Sample ID: NG-08G
---------------------------------------

Highest of AMPT, BENA, MICB, and OYST.
-----------------------------------
BENZOIC ACID                           1300    PPB X    DRY   2.00

Lowest of AMPT, BENA, MICB, and OYST.
-----------------------------------
4-METHYL PHENOL                         930    PPB X    DRY   1.39
BENZOIC ACID                           1300    PPB X    DRY   2.00

 Survey: EVCHEM    Station: NG-09
=================================

   Date: 10/03/86    Sample ID: NG-09G
---------------------------------------

Highest of AMPT, BENA, MICB, and OYST.
-----------------------------------
4-METHYL PHENOL                        2400    PPB      DRY   2.00
POLYCHLORINATED BIPHENYLS              5500    PPB E    DRY   2.20
PHENOL                                 2100    PPB      DRY   1.75

Lowest of AMPT, BENA, MICB, and OYST.
```

```
 ----------------------------------------

 Highest of AMPT, BENA, MICB, and OYST.
 ------------------------------------
 4-METHYL PHENOL                              2100     PPB       DRY   1.75

 Lowest of AMPT, BENA, MICB, and OYST.
 ------------------------------------
 4-METHYL PHENOL                              2100     PPB       DRY   3.13
 PHENOL                                       1200     PPB Z     DRY   1.79


  Survey: EVCHEM    Station: NG-15
 =================================

   Date: 10/15/86    Sample ID: NG-15G
 ----------------------------------------

 Lowest of AMPT, BENA, MICB, and OYST.
 ------------------------------------
 4-METHYL PHENOL                               760     PPB       DRY   1.13
 PHENOL                                        710     PPB Z     DRY   1.06


  Survey: EVCHEM    Station: OG-01
 =================================

   Date: 10/09/86    Sample ID: OG-01G
 ----------------------------------------

 Highest of AMPT, BENA, MICB, and OYST.
 ------------------------------------
 4-METHYL PHENOL                              1300     PPB       DRY   1.08

 Lowest of AMPT, BENA, MICB, and OYST.
 ------------------------------------
 4-METHYL PHENOL                              1300     PPB       DRY   1.94


  Survey: EVCHEM    Station: OG-02
 =================================

   Date: 10/09/86    Sample ID: OG-02G
 ----------------------------------------

 Lowest of AMPT, BENA, MICB, and OYST.
 ------------------------------------
 4-METHYL PHENOL                              1000     PPB       DRY   1.49


  Survey: EVCHEM    Station: OG-03
 =================================

   Date: 10/09/86    Sample ID: OG-03G    Field rep: OG03
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```
Survey: EVCHEM    Station: SR-04
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  Date: 10/06/86    Sample ID: SR-04G
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Lowest of AMPT, BENA, MICB, and OYST.
-----------------------------------
4-METHYL PHENOL                          980     PPB      DRY   1.46

 Survey: EVCHEM    Station: SR-05
=================================

  Date: 10/06/86    Sample ID: SR-05G
---------------------------------------

Highest of AMPT, BENA, MICB, and OYST.
------------------------------------
4-METHYL PHENOL                         2000     PPB      DRY   1.67
BENZOIC ACID                            1000     PPB      DRY   1.54

Lowest of AMPT, BENA, MICB, and OYST.
-----------------------------------
4-METHYL PHENOL                         2000     PPB.     DRY   2.99
BENZOIC ACID                            1000     PPB      DRY   1.54

 Survey: EVCHEM    Station: SS-01
=================================

  Date: 10/06/86    Sample ID: SS-01G
---------------------------------------

Lowest of AMPT, BENA, MICB, and OYST.
-----------------------------------
N-NITROSO DIPHENYLAMINE                   48     PPB      DRY   1.20

 Survey: EVCHEM    Station: SS-03
=================================

  Date: 10/06/86    Sample ID: SS-03G
---------------------------------------

Lowest of AMPT, BENA, MICB, and OYST.
-----------------------------------
4-METHYL PHENOL                          930     PPB      DRY   1.39
```